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DEVELOPMENT OF WELDING TECHNIQUES AND FILLER METALS FOR HIGH STRENGTH ALUMINUM ALLOYS

Progress Report Number 33
Ninth Quarterly Report
Project No. 1063-7

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to

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Purchasing Office
Huntsville, Alabama
Attn: PR-RDC

Contract No. NAS8-1529
Control No. TP2-85364

15 April 1964

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DEVELOPMENT OF WELDING TECHNIQUES AND FILLER METALS FOR HIGH STRENGTH ALUMINUM ALLOYS

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by

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Reporting Period
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FOREWORD

This report entitled, "Development of Welding Techniques and Filler Metals for High Strength Aluminum Alloys", was prepared by the Southwest Research Institute under Contract No. NAS8-1529 for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration.

The work was administered under the direction of the Propulsion and Vehicle Engineering Division, Engineering Materials Branch of the George C. Marshall Space Flight Center with Mr. Richard A. Davis acting as project manager.

ABSTRACT

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The mechanical properties of high strength, thick gage 2219 aluminum-copper alloy weldments are being investigated. This investigation includes both uniaxial and biaxial loading conditions. The failure mechanism in uniaxial and biaxial testing is also being studied. In addition, weld zone metallurgical phases are being studied and evaluated as to their influence on the mechanical properties.

Tensile specimens used in uniaxial testing suggest that the failure path in the weldment is dependent on the following:

1. The geometry of the specimen
2. The presence of a metallurgical notch, and probably
3. The occurrence of mismatch

On the microscopic scale the brittle nature of intermetallics is clearly shown in the fracture path. This suggests that the fracture path tends to follow the intermetallic constituents. The same features appear to apply to biaxial tests of welded panels.

Three 3/4" thick test panels have been satisfactorily hydraulically bulged. Two of these plates have been examined metallographically.

An analysis of strain in discrete locations across transverse weld tensile specimens has been made. These tests show that 57.1 percent of the strain in the commonly used two inch gage lengths occur in the weld deposit, 8.4 percent in the HAZ, and 12.9 percent in the parent metal.

Author

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A hydraulic bulge fixture was fabricated to evaluate 3/4" thick 2219-T87 aluminum weld panels under biaxial loading condition. Two such panels were fabricated for test.

Strain across welded joints was studied. Gage lengths were scribed in the weld deposit, HAZ and parent metal of transverse welded tensile coupons. By this technique, the distribution of strain was studied.

An explosive loading technique to increase the joint strength efficiency of weldments was evaluated. This technique showed that all weld metal yield strength can be increased about 138 percent. The yield strength of transverse weld tensile coupons was increased 43 percent by this technique.

II. INTRODUCTION

This report constitutes the Ninth Quarterly Report and is Progress Report Number 33 covering the period from 1 January 1964 to 31 March 1964 on high strength aluminum alloys.

This investigation is being conducted to evaluate the mechanical properties of high strength aluminum alloy weldments. It is planned to use this information in design consideration of the NASA Saturn program as well as future programs.

To obtain this objective, studies are being made of the following:

1. Microstructure and phases formed in the weld zones.
2. Failure mechanism of weldments under uniaxial and biaxial loading.
3. A study of mechanical properties of high strength Al-Cu alloy weldments is being made.

Emphasis during this reporting period has been stressed on the latter two objectives.

III. STUDY OF FAILURE MECHANISM IN ALUMINUM ALLOY WELDMENTS UNDER UNIAXIAL AND BIAXIAL LOADING

A. FAILURE MECHANISMS DUE TO UNIAXIAL LOADING

Considerable attention has been given to the mode of fracture of uniaxial tensile specimens. All weldments discussed in this report were fabricated in the horizontal position which gives rise to the terms "top toe" and "bottom toe." This is shown schematically in Figure 1. Note the manner in which the beads have been shown in this figure. The top and bottom toes of the beads are opposite each other. In another study, a panel was prepared in which the top and bottom toes were diagonally opposite; therefore, to distinguish between the two types the former has been designated as "normal panel." The presence of a brittle area in the toes of certain weldments has been previously reported in Quarterly Progress Reports 7 and 8, Contract No. NAS8-1529. This brittle metal has been found most frequently in the bottom "toes" of weldments. Several cracks have been noted in these areas after uniaxial tensile testing. It might be anticipated that these areas could provide initiation points for fracture. Assuming that this is the case, then it might be rationalized that the fracture path would be from bottom toe to bottom toe across the weldment, although this is not the case. Instead, specimens fracture diagonally across the weldment from bottom toe of one bead to top toe of the other bead. These specimens were from panels of the normal type and had the crowns intact.

All tensile samples previously tested throughout the course of this year's efforts have been examined to determine the fracture path. Without exception it has been observed that fracture initiates in the bottom toe of the first pass, then progresses diagonally to the top toe of the second pass. All these specimens contained the weld crowns intact and were of the normal type.

To further investigate the fracture path, a panel was welded in such a way that the bottom toe of the first pass diagonally opposed the bottom toe of the second pass. This was accomplished by inverting the panel after depositing the first weld pass. This type of panel has been designated as "Inverted Panel." This produced fracture that initiated in the top toe of the first pass and then propagated diagonally to the top toe of the second pass.

It is not known exactly why the specimens fractured in this manner, although further evaluations will be made to try and determine the cause of this unusual fracture.

To determine what effect weld crown removal would have on mode of fracture, three specimens were prepared and tested. These specimens were prepared from panels prepared in the normal manner. That is, the top toes and bottom toes of the beads were opposite each other as shown in Figure 1. The fractured surface was perpendicular to the long axis of the specimen rather than the usual diagonal fracture that occurs when the crowns remain intact. It is felt that the change in geometry was the direct result of the change in fracture path.

The fracture path of the three types of specimens are shown in Figure 2.

Fracture path was also studied on round tensile specimens. All tensile tests discussed previously have been of a rectangular cross section. It is interesting to note that fracture initiated in the bottom toe of the first pass and propagated to the top toe of the second pass. This is shown in Figure 3. These specimens were machined from a panel prepared in the normal manner. It may be recalled that this is the same mode of fracture for the rectangular tensile specimens of the normal type.

Tensile coupons were machined from a welded panel in such a way that the coupons contained only one of the weld beads. This is schematically shown in Figure 28. Although these specimens were prepared to study elongation properties, it is interesting to note the fracture path of the broken specimens. Note in Figure 4 that fracture propagated diagonally across weld metal.

A gap has been noted in the first pass after butting the two halves of a broken tensile coupon together. This gap is shown in Figure 5 and in the middle photograph of Figure 2. The fact that a gap exists indicates that the first pass is less ductile and fractures first in a tensile test. The second pass being more ductile continues to elongate a few mils before it breaks. The presence of such a gap is further discussed in Section IV of this report in which studies were conducted on the extensions across weldments.

From the information thus far obtained, it appears that three factors could influence the mode of fracture: namely, 1) geometry of specimen,

2) metallurgical notch and, 3) possible mismatch. Additional work will be conducted to try and obtain a better understanding of fracture mechanisms.

B. METALLOGRAPHIC STUDIES OF FRACTURED UNIAXIAL SPECIMENS

Previous studies have been directed at locating the presence of cracks just prior to complete failure in tensile specimens. Although such cracks have been observed in the toes of weld, it was also hoped that the initial stages of fracture could be seen further down in the weld metal. This would in effect indicate if the crack propagated in the intermetallic inclusion. To make this examination, the weld area was polished down in the transverse direction of the weld. It was felt that should cracks be present, they would be detected more readily in this direction. Although there has been some evidence of cracking when observed at very high optical magnification (1500 to 2000X), the results were not conclusive.

Because no conclusive results could be drawn from the studies made, it was then decided to examine the edges of fractured tensile specimens. The appearance of the fracture edge suggested that the path of crack was influenced by the presence of intermetallic constituents. In other words, the fracture tended to follow the path of intermetallic compounds. During this examination, it was noted that small cracks could be seen in the edge of the weldment which were definitely associated with the major fracture surface. It appeared that these cracks formed as the specimen was failing and propagated a short distance at nearly right angles from the major cracks. Four specimens containing these cracks were examined. In all cases it was noted that the crack followed intermetallic compounds which in most cases are highly concentrated in the grain boundaries. This is clearly seen in Figure 6. Based on this study, it can be concluded that fracture follows the path of intermetallic compounds.

C. BIAXIAL LOADING BY HYDRAULIC BULGE TESTING

The hydraulic bulge test is being used in a study of the fracture characteristics of full thickness (3/4") 2219-T87 weldments subjected to biaxial loading. Three panels were tested to rupture during this quarter and a metallurgical investigation of the fractured areas has been carried out. The results of the metallurgical investigation of two of these panels are given in Section IV-D.

1. Preparation of Test Panels

The three panels tested were prepared as follows:

Panel No. 41 was fabricated by butt-welding two 32 x 16 x 3/4" plates. Welding was performed by the Automatic Tungsten Inert Gas Process with one pass deposited from each side. The welding variables are listed in Figure 7. To prepare the panel for hydraulic bulge test, twenty 7/8" diameter holes were drilled around the periphery of the panel. In addition, the weld crowns were ground off in the clamping area. Prior to testing, the panel was radiographed 100 percent.

Panel No. 42 was prepared and contained a "Tee" weld simulating the intersection of a longitudinal and circumferential joint in a cylindrical pressure vessel. Two 18 x 16 x 3/4" plates were butt welded together using the same welding procedure used for Panel No. 41.

After radiographic inspection, the section was cut to the 32 x 16 x 3/4" size needed for the final welding operation. This section was then butt welded to a 32 x 16 x 3/4" plate to form the final panel. After radiographic inspection, the weld crowns were removed in the clamping area and the 3/4" diameter holes were drilled around the periphery.

Panel No. 46 was fabricated in the same manner as Panel No. 41 with the following exceptions:

a. Two passes deposited on each side of the plate. Welding variables are listed in Figure 8.

b. Weld crown ground off flush with plate surface on both sides of panel.

The completed panels were strain gaged upon completion of fabrication and nondestructive testing. Three-gage rosettes were mounted in the weld metal, heat affected zone, and adjacent base metal to monitor strain during testing.

2. <u>Hydraulic Bulge Testing Procedure</u>

The hydraulic bulge testing fixture consists of a top and bottom die between which the test panel is placed. The top die has a 24" diameter opening into which the panel bulges as hydraulic pressure is applied at the panel-bottom die interface. The mechanical hold-down pressure is supplied by twenty 3/4" diameter high strength steel bolts located around the periphery of the fixture.

The testing procedure consists of placing the test panel between the top and bottom dies and bolting the entire fixture together. The fixture is then pressurized incrementally until rupture occurs.

Strain gage readings were recorded by a Minneapolis-Honeywell Model 906 A-1 Visicorder Oscillograph with Honeywell Type M 200-120 galvanometers having a sensitivity of 1:21 millivolts per inch deflection and a frequency response of 0-12 cycles per second. The output of a pressure transducer located in the inlet side of the hydraulic system was also recorded by the visicorder.

3. Test Results

The hydraulic bulge testing technique proved to be an effective method of subjecting full thickness 2219-T87 weldments to biaxial loading. The three panels described were tested to rupture as planned. These fractured panels were examined to determine whether the fracture characteristics of full thickness weldments are comparable under uniaxial and biaxial loading conditions. It should be pointed out that the only other method available for obtaining similar data in full thickness 3/4" weldments would be the rupture testing of full thickness pressure vessels or cylinders. The cost of fabricating such test vessels greatly exceeds that of fabricating test panels for hydraulic bulge testing.

Listed below are the data obtained from the three bulge tests.

Panel Identification	Pressure to Rupture (psig)	Bulge Height (inches)
Panel No. 41, Single Butt Weld. Crown Intact.	805	*
Panel No. 42, "Tee" Weld. Crown Intact.	1,028	.788
Panel No. 46, Single Butt Weld. Crown Ground Off.	882	.656

Although no conclusive results can be drawn from only three tests, there is an indication that possibly the "Tee" weld panel is stronger than the two panels with single welds through the center. The "Tee" weld panel (Number 42) required a pressure of 1,028 psig for rupture as compared to 805 psig and 882 psig for the two panels containing single welds through the center.

Sectioning of the panels after testing revealed that the three welds had incomplete penetration of varying severity throughout their entire length. This condition was not detected in the radiographic inspection of the panels conducted prior to machining. In spite of this defect in the weldments, the greater pressure to rupture sustained by Panel No. 42 ("Tee" weld) appears to be significant. This panel also exhibited considerably more deformation than the panels made up with a single welded joint.

In addition to biaxial hydraulic bulge tests, transverse weld uniaxial tensile specimens were machined from the flat hold down areas of Panel No. 46 and tested.

*Not recorded.

The results of these tests are tabulated below:

Specimen No.	Yield Strength (psi)	Ultimate Strength (psi)	% Elongation in 2 inches
46-1	24,800	30,800	3.4
46-2	28,400	32,400	3.4
46-3	25,000	38,500	5.0
46-4	23,100	34,900	5.5
Average	25,300	34,200	4.3

As mentioned above all three panels contained incomplete fusion which accounted for the low uniaxial mechanical properties.

Based upon the information thus far obtained from the hydraulic bulge tests, additional work should be carried out to confirm the apparent increased load carrying capacity of the "Tee" weld configuration and also determine whether a panel containing a "Cross" weld would have even greater load carrying capacity. In addition, tests could be made to compare filler wires and the effect of weld crown. Of equal importance is the potential of evaluating welding procedures, defects, and repair procedures.

D. FAILURE MECHANISMS DUE TO BIAXIAL LOADING (HYDRAULIC BULGE TEST)

The three bulge plates examined were:

Panel No. 41 - Single butt weld. Crown intact.

Panel No. 42 - "Tee" weld. Crown intact.

Panel No. 46 - Single butt weld. Crown ground off.

The measurements and location of the surface cracks for each plate are shown in Figures 9, 10 and 11 respectively. The photographic appearance of the outer surface of Panel No. 41 is shown in Figure 12. Shown in Figure

13 is the inner surface of the same panel.

A common feature of all three tests was the fracture path on the surfaces of the plate. This was in the weld metal heat affected zone area. In addition, as would be expected, the length of the crack on the outer surface of the plates was greater than on the inner surfaces for all the panels.

The panel containing the "Tee" weld was shipped to Mr. Richard Davis, Project Leader, at MSFC, Huntsville, Alabama for sectioning and further examination. The other panels were examined at Southwest Research Institute. The information obtained was as follows:

1. Examination Procedure

Segments of the panels containing the surface cracks were removed from the panels. These segments were then sectioned at 1/2" intervals. This provided a series of cross sections showing varying depths of the cracks and also their locations. The depth below the surface was measured with calipers for each cross section.

Sections of interest were mounted for metallographic examination. These metallographic sections included the ends of the crack as viewed from the outer surface as well as where complete fracture had occurred. These were examined to study the initiation points and path followed by the crack.

2. Results

a. Square Butt Welded Panel No. 41, One Pass From Each Side

As noted in Figure 9, this plate exhibited an outer surface crack 13-1/2 " in length. The inner surface crack was 4-1/2" long. Figure

14 shows the cross sections through the ends and center of the rupture. Fracture initiated on the outer surface in the bottom toe of the first pass. The crack propagated to the top toe of the second pass. This pattern was uniform along the length of the rupture.

The profile of this rupture obtained by measurements of its depth at 1/2" intervals is shown in Figure 15. This suggests that as the crack formed on the outer surface it readily propagated through the weld metal to a considerable depth (approximately 1/2") where lack of penetration was present. The change in the crack profile in the lower portion of Figure 15 may be the result of the lack of penetration acting as a crack arrester.

A microscopic examination of the outer weld crown where the surface crack terminated was made. This showed a series of surface fissures occurred in a region of intermetallic precipitates. These intermetallic precipitates have been identified to be basically $CuAl_2$ and β (Al-Cu-Fe) as was reported in the Eighth Quarterly Report, Contract No. NAS8-1529.

Figure 16 is a cross section of an area of the bottom "toe" in the first weld pass. This was the location of the rupture crack in the outer surface of Panel No. 41. The region shown was at an extreme end of the rupture. Three small cracks can be seen in this figure. The one labeled major "fissure" was identified as being associated with the rupture path through the plate. Thus, Figure 16 provides an indication of the initial direction taken by the rupture. More details of the relationship between the fissure and its path through the intermetallic precipitates in the weldment is seen in Figure 17 which is a higher magnification of the same fissure.

Figure 18 shows a cross section of the rupture at the outer surface. Figure 19 illustrates the path of the rupture as seen looking down on top of the outer surface of the bulged panel. The rupture is seen to follow a path in the weld metal very close to the HAZ weld metal fusion line (toe of weld).

The mode of fracture was studied by examining the ends of the crack. Shown in Figure 20 is the fracture as it progressed through the weld metal under the influence of biaxial loading. These features may be summarized as follows: 1) the crack follows an irregular path through the metal, and 2) the preferred path of the crack appears to be through intermetallic precipitates. It may be recalled that the features of this crack are quite similar to those of the cracks in uniaxial specimens.

b. Butt Welded Panel No. 46, Two Passes From Each Side

From Figure 11, it will be noted that the outer surface crack was 11-5/8" long and on the inner surface extended 5-3/4". The crack initiated in the bottom "toe" of the second pass and extended through the weldment to emerge in weld metal close to the bottom toe of the first pass on the inner surface. This crack path on the macroscopic level was markedly different from that of the other butt weld panel studied. Two factors contributing to this difference appear to be 1) the filler passes in the top toe of both weld passes, and 2) the fact that the crowns were removed by grinding.

The difference between these fracture paths in Panel Nos. 41 and 46 may be significant in view of the studies in fracture paths in uniaxial specimens. Uniaxial specimens with crowns off failed through the weld metal and perpendicular to the long axis of the specimen.

Cross sections through the crack provided details for the plot of crack profile in Figure 21. This once again indicated that the fracture forming on the outer surface progressed readily through the weldment until it reached a depth where lack of penetration existed. Again, as noted in the discussion of Panel No. 41, the change in crack profile in the lower portion of Figure 21 may be the result of lack of penetration acting as a crack arrester. Figure 22 contains macrographs of the ends and center portions of the fracture. This shows that fracture initiated in the bottom toe of the second pass and propagated through the weld to the bottom toe of the first pass. The most likely explanation for this difference in fracture path is the addition of the filler passes in Panel No. 46. These extra passes which appear to alter the fracture path may be an effective means of increasing the maximum pressure required to rupture the panels; therefore, additional tests should be made to further investigate this possibility.

Metallographic studies of the cross section of the bottom toe of the second pass where fracture initiated were made. Small cracks similar to the ones noted in Figure 16 were not detected in this examination, probably because a portion of the toe was removed when the crown was ground flush with the base metal.

IV. METHODS OF MEASURING YIELD STRENGTH AND DUCTILITY OF WELDS

A. YIELD STRENGTH

A study of uniaxial yield strength has been reported in the Seventh and Eighth Quarterly Reports, Contract No. NAS8-1529. Considerable effort has been utilized in this reporting period to determine biaxial yield strength from the three hydraulic bulge tests. It was planned to compare these results with those obtained from uniaxial tests. Efforts to make this yield strength determination from the bulged test have been unsuccessful. This can be attributed to two reasons: 1) insufficient bulge to apply the membrane stress formula, and 2) insufficient weldment to obtain all weld metal tensile specimens. Originally, it was planned to determine yield strength from the membrane stress formula (Discussed in Eighth Quarterly Report) but due to insufficient bulging occurring in the 3/4" thick panels this criteria of evaluating stress could not be used. Because this method was not applicable, an alternate approach was considered. The Von Mises yield criteria was studied and found to be applicable for this test. To evaluate biaxial yield strength of a material by Von Mises yield criteria requires that the uniaxial yield strength determination be made and, using this information, biaxial yield strength can be calculated. For the particular tests under consideration, it would be necessary to make all weld metal uniaxial yield strength determinations to correctly evaluate biaxial weld metal yield strength; therefore, because sufficient welded material was not available to make all weld metal uniaxial yield strength, this property could not be determined.

Consideration was given to using uniaxial yield strength data from previous weldments, however this idea was rejected because of the error that would be introduced in using the uniaxial yield strength from one weld and applying this information to the calculations of biaxial yield strength in another weld. Should additional bulge tests be made then the Von Mises yield criteria could be used to evaluate biaxial yield strength.

In addition to the yield strength study, effort was directed toward evaluating biaxial ultimate strength from the bulge tests. Although the hydraulic bulge test is used to determine the biaxial mechanical properties of thin gage material, it is not applicable in this case due to the thickness and lack of sufficient bulge in the 2219-T87, 3/4" thick panels.

Because of the difficulties involved in determining biaxial ultimate strength from the hydraulic bulged panels, it was decided to make a preliminary investigation into other tests for determining this property. General Atomics, San Diego, California is presently studying biaxial stress in pressure vessel steels. They have designed a tubular specimen capable of developing a tangential to axial stress ratio of 1:1. It is possible that this specimen would be applicable in the evaluation of biaxial stress of the aluminum welded panels but it is felt that a considerable amount of development work would be required before useful information could be obtained. For this reason another type of specimen developed by Massachusetts Institute of Technology has been tested. This specimen is a modified rectangular tensile specimen and is reported to develop a 2:1 biaxial stress ratio.[56] This specimen is shown in Figure 23.

It should be pointed out that neither of the two tests considered represented the full thickness of the weldment. This could affect the resultant mechanical properties. The location from which these specimens were machined from the 3/4" thick welded panels is shown in Figure 24. Strain gages were mounted on each side of two of the specimens to measure strain in the axis of maximum strain. The third specimen was not strain gaged; therefore, only maximum stress was recorded. A gage was mounted on each side of the specimens to measure any bending moment that might develop during the tests. These tests did not indicate such a bending moment. The mechanical properties of these tests are tabulated below:

Specimen No.	Yield Strength (.2% Offset), psi	Ultimate Strength (psi)
B33-1	15,000	40,200
B33-2	14,500	36,100
B33-3	*	40,100
Average	14,300	38,800

A single parent metal test was also made and the resultant ultimate strength was 71,980 psi. Stress-strain curves in the major stressed axes of specimens B33-1 and B33-2 are shown in Figures 25 and 26. It should be pointed out that the preceding yield strengths were obtained from the stress-strain curves at .2 percent offset. Actually the 2:1 biaxial stress condition is not developed in the specimen until a strain of 1 percent has been reached. This means that the specimen was not in a 2:1 stress condition at the .2 percent yield strength but rather some value between uniaxial and 2:1.

*Not recorded.

For comparative purposes uniaxial specimens were tested with the weld crown machined off. This tends to simulate the test specimen used for biaxial test. The results of these tests are shown below:

Specimen No.	Yield Strength (.2% Offset), psi	Ultimate Strength (psi)
33-A	21,300	40,900
33-B	22,200	41,000
33-C	21,800	41,000
Average	21,770	40,970

A comparison of the biaxial properties with the uniaxial mechanical properties indicates that possibly the latter properties are a little higher. Information from the literature [46*, 56] suggests this is not the case but rather the biaxial ultimate strength to be from 5 to 15 percent higher.

One possible explanation for the difference in properties is the location the biaxial specimens were machined from the weldment. It can be seen in Figure 24 that the biaxial specimens represent only a small portion of the total thickness of the weldment but a considerable amount in the direction of the long axis of the weld. In contrast, the uniaxial specimen represents the full thickness of the weldment except for the weld crowns being ground off and a small portion in the direction of the long axis of the weld. It should be pointed out that these tests are by no means conclusive

*Corrigan, D.A., Travis, R.E., Ardito, V.P., and Adams, C.M., Jr.: "Biaxial Strength of Welds in Heat Treated Sheet Steel." Welding Journal, Research Suppl., 1962, 41 (3), pp 123-S to 128-S.

The bibliography of this article may be found in the Seventh Quarterly Report, Contract No. NAS8-1529.

and that additional tests would have to be made to either verify or reject these findings.

Because this specimen does not represent the full cross section of the weldment, it is not considered a truly valid test for biaxial mechanical properties of the welded joint. It is therefore recommended that additional tests not be made using this type specimen.

In the preceding Eighth Quarterly Report,Contract No. NAS8-1529, it was stated that the overall strain across a welded joint would be studied by birefringent coating, photostress technique. Although some of these tests have been completed, additional studies should be made. It is planned to make these studies during the next quarterly reporting period.

B. DUCTILITY

Surveys of the various regions contributing to the overall extension reported in the Eighth Quarterly Report (Contract No. NAS8-1529) indicated that elongation over the 2" gage length was the result of approximately:

1. 21.6 percent strain in the weld metal
2. 7.3 percent strain in the HAZ
3. .3 percent strain in the base metal

The areas surveyed in five new tests were:

a. Through the first weld

b. Through the second weld

c. Through the center line of the specimen

These surveys are schematically shown in Figure 27. Mechanical properties of the specimens are tabulated in Table I. These properties were determined with the weld crown intact. Table II summarizes the average percent strain in each zone of each specimen. The overall average of each zone was 19.6 percent strain for the weld metal, 8.7 percent strain in HAZ, and 0.97 percent strain in the base metal. Calculating the contribution by each zone to the total extension showed that 57.1 percent of the overall extension is derived from the weld metal, 8.4 percent from the HAZ, and 12.9 percent from the base metal. It will be recalled that two previous specimens tested (reported in Eighth Quarterly Report) indicated that the weld metal contributed about 80 percent of the extension across the 2" gage length. In these two specimens, consideration was not given to the gap which occurred across the fracture after the two broken pieces were mated together. These two initial specimens were tested merely to derive some idea of the magnitude of strain in the different zones.

Strain distribution is provided by the results of the three surveys per specimen contained in Table III. These tables are arranged to indicate each zone measured and its length before and after testing. The percentage of calculated strain for each zone is also shown. The final column in Table III states the percentage of the overall gage length extension represented by the extension of each zone measured. Theoretically, the summation of the extensions of these zones should equal 100 percent for any given survey. However, this is not the case for two reasons: 1) accuracy of determining overall increase in length. This increase in length was found by using calipers to measure previously scribed gage marks. Reproducibility was $\pm$ .005" which could account for a 5 percent error in the last column. Although the calipers were accurate to within .001", the problem in reproducibility arose from not being able to match up the broken sample exactly the same each time. All other measurements were made with a traveling microscope which was read to the closest mil indication. 2) Different ductility exists in the first and second weld passes. From an examination of Table III in the "Percentage Strain for Each Zone" column, it will be noted that the percent strain in the weld metal varies from 12.5 to 26.2 percent. An indication of this difference has previously been noted when the fractured faces of the tensile specimen were mated together. A gap has often been observed and most frequently occurring in the first weld pass.

To assess the individual properties of the first weld pass as separated from the second weld pass, special specimens were fabricated. This involved splitting a standard tensile specimen into two smaller tensile specimens. This provided an uniaxial tensile specimen out of each of the first and second weld passes. The specimen configuration is shown in Figure 28.

Three tensile specimens were split in this manner to provide three first pass specimens and the matching three second pass specimens. The mechanical properties obtained for these specimens are shown in Table IV. Averaging the mechanical properties indicated higher elongation in the second pass than in the first pass.

The summary of the strain measurements in these specimens is contained in Table V. The weld has previously been found to be the area contributing most of the strain in the overall 2" elongation measurement. This again is indicated by the results in Table VI. The average strain occurring in the weld area is 25.9 percent for the first pass, 27.9 percent in the second pass as shown in Table V. This is in comparison with 19.6 percent for full 3/4" thick weld specimens as noted in Table II. The higher values are believed to be the result of straining each weld pass separately. In a normal two pass weldment, a composite structure exists. It appears that the lower strain value existing in the first weld pass results in fracture initiation in this weld pass. The gap mentioned in the footnote of Table II indicates that there is a time lapse between the crack formation in the first pass and total failure of the specimen. This gap is shown in the middle photograph of Figure 2 and also in Figure 5.

Further studies of strain are presently underway. It is hoped that the information generated by these studies will provide a basis for the definition of yield in the 2219 weldments.

V. LITERATURE SURVEY

BIBLIOGRAPHY

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60. Forsyth, P. J. E. and Ryder, D. A.: "Some Results of the Examination of Aluminum Alloy Specimen Fracture Surfaces". Metallurgia, Vol. 63, No. 377, March 1961, pp 117-124.

"COMBINED STRESS EXPERIMENTS ON A NICKEL-CHROME-MOLYBDENUM STEEL"*

Lessels - MacGregor

The authors describe a tubular specimen for obtaining uniaxial and biaxial stresses. To obtain biaxial stress internal pressure was applied to the specimen. A wide range of biaxial stresses can be obtained with this type of specimen by the application of both tensile load and internal pressure.

This type specimen was considered as a means of checking the stresses developed in the hydraulic bulge welded panels.

* Abstract of Article No. 52 as noted in Bibliography.

"NEW HIGH STRENGTH ALUMINUM ALLOY IS TOUGH, WELDABLE"*

- - -

This article describes a relatively new high strength aluminum alloy designated as 7039. A comparison was made between this alloy, 2219, 5083 and 2014. The 7039 alloy was reported to have good cryogenic properties and will be quite useful for ordnance and missile structures. At 75° and -350°F the strength of 7039-T6 was found to be superior to 2219-T81 and 5083-H113 in both strength and notched-unnotched strength ratio. At 75°F, 7039-T6 was slightly lower in strength than 2014-T6, but had a slightly higher notched-unnotched tensile strength ratio. At -320°F the tensile strength and notched-unnotched tensile strength ratio was about the same.

Fatigue strength of 7039-T6 was superior to the other alloys studied. After 10^8 cycles, the fatigue strength of 7039-T6 was approximately 5,000 psi higher than the 5083-H113, and almost 12,000 psi higher than the 2219-T81.

The weldability was reported to be quite good from the standpoint of resistance to cracking. A comparison was made between 7039, 7079 and 2219. These tests showed that 7039 was superior.

*Abstract of Article No. 53 as noted in Bibliography.

"THE DEFORMATION BEHAVIOR OF SOME ALUMINUM ALLOYS CONTAINING INTERMETALLIC COMPOUNDS"*

Petty

Tensile and rolling tests were made on aluminum alloys containing various dispersions of $CuAl_2$ and $FeAl_3$. This study showed the importance of size, shape and amount of the phases on strength, plasticity and deformation over a range of temperatures. Tensile test of alloys containing 1.9 and 10 percent Fe resulted in equal strengths at all temperatures up to about 500° C. In fact, at temperatures above 400°C these alloys were stronger than alloys containing up to 40.4 percent Cu.

The iron alloys were rolled at temperatures up to 500° to investigate the plasticity of the particles. Samples were then examined metallographically. Little difference was noted in the behavior of the $FeAl_3$ particles. Of particular interest were micrographs of $FeAl_3$. These particles were relatively large and rectangular in shape.

*Abstract of Article No. 54 as noted in Bibliography.

"EFFECTS OF CHILLING DURING WELDING ON THE STATIC AND FATIGUE PROPERTIES OF H30 ALUMINUM ALLOY"*

Adams - Dinsdale

The effect of modifying the heat-affected-zone of a 1/4 inch thick aluminum-manganese-silicon alloy by water chilled back up bars was studied. It was noted that static joint strength could be increased by 6,000 psi by this technique. Hardness surveys were made in the weld, HAZ and base metal of the material welded with the water chilled back up bar and compared with normally welded joints. This test also verified the fact that the HAZ could be greatly modified.

Fatigue tests were made and the results showed that fatigue strength was not affected. It was noted that post-weld aging of welds with the reinforcement left on, reduced the fatigue strength by 16 percent. The strength was improved slightly by removing the crown, although a complete analysis could not be made due to porosity inclusions.

*Abstract of Article No. 55 as noted in Bibliography.

"TENSILE TESTING WITH A BLUNT NOTCH"*

- - -

Under this topic of the first section of the Welding Handbook, The Massachusetts Institute of Technology biaxial tensile test specimen is described. It is reported here that, experimentally, the increase in ultimate strength of high strength is between 5 and 15 percent as a result of using this type specimen. In addition, drawing of the test is shown. The effect of specimen geometry on tensile strength is illustrated by curves. A specimen width about 25 to 30 times the slot thickness is required for maximum tensile strength.

*Abstract of Article No. 56 as noted in Bibliography.

"FUSION-ZONE STRUCTURES AND PROPERTIES IN ALUMINUM ALLOYS"

Brown - Adams, Jr.

A study of the fusion zone in 2014 arc deposits was made. The relationship between finer dendritic size and lower heat input was established. It was noted that arc deposits represent more severe quenching rates than any form of chill casting. Time of solution treatment was reduced and ductility improved when the lower levels of heat input were used.

*Abstract of Article No. 57 as noted in Bibliography.

"THE ELECTRON MICROSCOPE -- A NEW TOOL FOR EXAMINING FRACTURES"*

Phillips - Bennet

The greater depth of focus resolution and obtainable magnification of the electron microscope over the optical microscope can be used in fracture studies. The 200,000X for the electron microscope as compared to the 2,000X of the optical indicates that many details hitherto undetermined can be revealed. A replica of the fractured surface was made and examined. Fatigue, shear, ductile and brittle failures can be identified by this technique.

*Abstract of Article No. 58 as noted in Bibliography.

"ALUMINUM AND ITS ALLOYS IN 1960"*

Elliot

This review of aluminum highlights, 254 references, deals with all aspects of the metal for its extraction and fabrication through its properties. Developments in MIG and TIG welding are noted, and literature dealing with weld failure is also included.

*Abstract of Article No. 59 as noted in Bibliography.

"SOME RESULTS OF THE EXAMINATION OF ALUMINUM ALLOY SPECIMEN FRACTURE SURFACES"*

Forsyth - Ryder

This paper discusses the use of the electron microscope as applied in fractography of aluminum alloy failures. Brittle intercrystalline tensile fracture was one of the types of failure examined and theory for its occurrence is advanced.

*Abstract of Article No. 60 as noted in Bibliography.

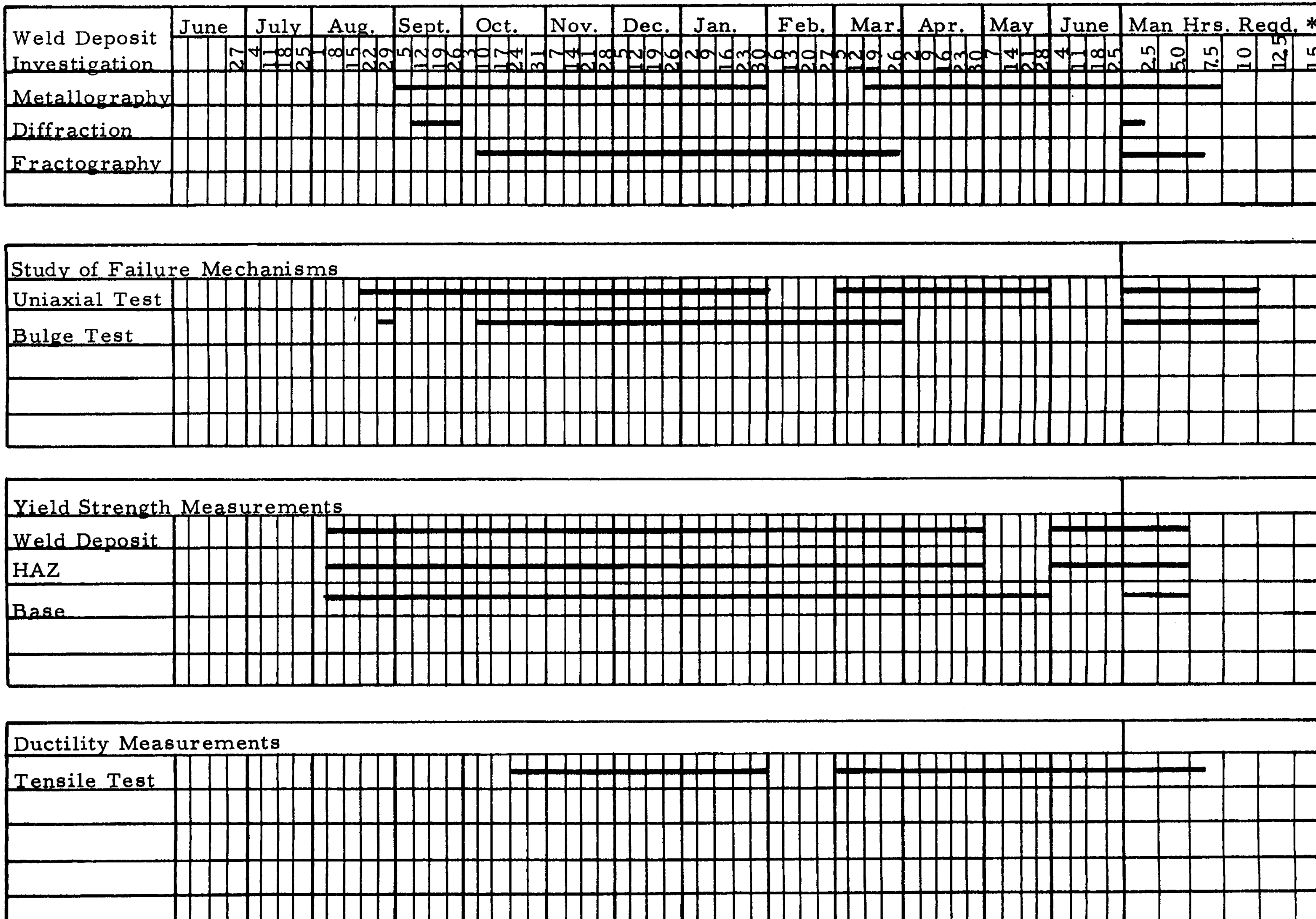
VI. WORK ACCOMPLISHED DURING LAST MONTHLY PERIOD

During the last month evaluation of the welded bulged panels was completed. A considerable amount of work was done on the mode of fracture of both uniaxial and biaxial tests. In addition, the distribution of strain study across welded joints was continued.

A study was made of a biaxial test developed by Massachusetts Institute of Technology.

VII. PROGRAM PLANNING CHART NO. 9

OVER-ALL OBJECTIVE INVESTIGATION OF WELDING TECHNIQUES FOR HIGH STRENGTH ALUMINUM ALLOYS



* Man Hours Required (x100)

VIII. PURCHASES

Items	Date Ordered	Date Received	Cost
3/4" 2219-T87 Al	7-31-63	9-23-63	$1,460.00
Strain Gages	9-9-63	9-20-63	528.00
Strain Gages	9-28-63	10-9-63	256.00

IX. ANTICIPATED WORK

I. Run additional bulge tests.

II. Continue ductility study of weldments.

TABLES

TABLE I

MECHANICAL PROPERTIES OF SPECIMENS FROM 3/4 INCH THICK 2219-T87 ALUMINUM WELDMENTS USED IN DUCTILITY MEASUREMENTS[1]

Specimen	Yield Strength (0.2% offset) psi	Tensile Strength psi	Percent Elongation (in 2 inches)
27-2	22,900	43,100	5.25
27-3	22,900	43,400	6.15
33-4	23,100	43,000	6.20
33-5	22,800	44,000	6.20
33-6	23,700	43,800	5.60
Average	23,080	43,460	5.88

[1]Horizontal square butt weld one pass from either side.

TABLE II

SUMMARY OF AVERAGE STRAIN IN WELD METAL, HAZ, AND BASE METAL OF WELDED 3/4 INCH THICK 2219-T87 ALUMINUM TENSILE SPECIMENS

Specimen	Average Percent Strain in Weld Zones[1]			Percent Elongation Over 2 Inch Gage Length
	Weld Metal Average Strain (Percent)	HAZ Average Strain (Percent)	Base Metal Average Strain (Percent)	
27-2	21.2	6.8	1.09	5.25
27-3	19.9	9.6	0.95	6.15
33-4	18.9	10.1	0.38	6.20
33-5	20.5	8.7	1.09	6.20
33-6	17.3	8.7	1.33	5.60
Average	19.6	8.7	0.97	5.9
Percentage of total extension across welded joint(2" gage length) contributed by each zone	57.1*	2.(4.2*)= 8.4	12.9*	100.0

*The summation of these values is not 100 percent. This is the result of the gap occurring across the fracture

[1] Percent Strain = $\frac{\Delta \ell}{\text{initial length}} \times 100$

TABLE III

COMPARISON OF STRAIN MEASUREMENTS IN A 3/4 INCH THICK 2219-T87 ALUMINUM WELDMENT AS DETERMINED BY SURVEYS THROUGH THE FIRST WELD PASS, CENTER LINE OF THE WELD, AND THE SECOND WELD PASS

Specimen 27-2

Survey	Zone	Initial Length (Inches)	Final Length (Inches)	Measured Extension (Inches)	Percent Strain for Each Zone[1]	Percent of Total Increase in Length Across the Weldment (2 Inch Gage Length) Contributed by Each Zone
Overall Measurement	2 Inch Gage Length	2.000	2.105	.105	5.25	100.0
First Weld Pass	Weld Metal	.364	.426	.062	17.0	59.0
	Top HAZ	.058	.062	.004	6.9	3.8
	Bottom HAZ	.050	.052	.002	4.0	1.9
	Base Metal	1.529	1.552	.023	1.5	21.9
						Σ 86.6
Center Line through Weldment	Weld Metal	.275	.345	.070	25.5	66.7
	Top HAZ	.033	.036	.003	9.1	2.9
	Bottom HAZ	.038	-	-	-	-
	Base Metal	1.654	1.666	.012	.72	11.5
						Σ 81.1
Second Weld Pass	Weld Metal	.380	.462	.082	21.6	78.2
	Top HAZ	.055	.059	.004	6.7	3.8
	Bottom HAZ	.063	.068	.005	7.3	4.8
	Base Metal	1.502	1.518	.016	1.06	15.2
						Σ102.0

[1] Percent strain = $\frac{\Delta \ell}{\text{initial length}} \times 100$

TABLE III

COMPARISON OF STRAIN MEASUREMENTS IN A 3/4 INCH THICK 2219-T87 ALUMINUM WELDMENT AS DETERMINED BY SURVEYS THROUGH THE FIRST WELD PASS, CENTER LINE OF THE WELD, AND THE SECOND WELD PASS (Cont'd)

Specimen 27-3

Survey	Zone	Initial Length (Inches)	Final Length (Inches)	Measured Extension (Inches)	Percent Strain for Each Zone	Percent of Total Increase in Length Across the Weldment (2 Inch Gage Length) Contributed by Each Zone
Overall Measurement	2 Inch Gage Length	2.000	2.123	.123	6.15	100.0
First Weld Pass	Weld Metal	.366	.415	.049	13.4	39.9
	Top HAZ	.057	.060	.003	5.3	2.4
	Bottom HAZ	.060	.066	.006	10.0	4.9
	Base Metal	1.516	1.531	.015	.99	Σ 59.4
Center Line through Weldment	Weld Metal	.289	.363	.074	25.6	60.2
	Top HAZ	.037	.041	.004	10.8	3.3
	Bottom HAZ	.047	.052	.005	13.5	4.1
	Base Metal	1.627	1.633	.006	.37	4.9
						Σ 72.5
Second Weld Pass	Weld Metal	.373	.447	.074	19.7	60.1
	Top HAZ	.056	.062	.006	10.7	4.9
	Bottom HAZ	.069	.074	.005	7.2	4.1
	Base Metal	1.502	1.524	.022	1.5	17.9
						Σ 87.0

TABLE III

COMPARISON OF STRAIN MEASUREMENTS IN A 3/4 INCH THICK 2219-T87 ALUMINUM WELDMENT AS DETERMINED BY SURVEYS THROUGH THE FIRST WELD PASS, CENTER LINE OF THE WELD, AND THE SECOND WELD PASS (Cont'd)

Specimen 33-4

Survey	Zone	Initial Length (Inches)	Final Length (Inches)	Measured Extension (Inches)	Percent Strain for Each Zone	Percent of Total Increase in Length Across the Weldment (2 Inch Gage Length) Contributed by Each Zone
Overall Measurement	2 Inch Gage Length	2.000	2.124	.124	6.2	100.0
First Weld Pass	Weld Metal	.375	.422	.047	12.5	37.9
	Top HAZ	.055	.058	.003	5.5	2.4
	Bottom HAZ	.053	.058	.005	9.4	4.0
	Base Metal	1.517	1.522	.005	0.33	4.0
						Σ 48.3
Center Line through Weldment	Weld Metal	.299	.361	.062	20.7	50.0
	Top HAZ	.054	.059	.005	9.3	4.0
	Bottom HAZ	.035	.042	.007	20.0	5.6
	Base Metal	1.612	1.614	.002	0.12	1.6
						Σ 61.2
Second Weld Pass	Weld Metal	.379	.468	.089	23.5	71.8
	Top HAZ	.074	.081	.007	9.5	5.7
	Bottom HAZ	.071	.076	.005	7.0	4.0
	Base Metal	1.476	1.486	.010	0.68	8.1
						Σ 89.6

TABLE III

COMPARISON OF STRAIN MEASUREMENTS IN A 3/4 INCH THICK 2219-T87 ALUMINUM WELDMENT AS DETERMINED BY SURVEYS THROUGH THE FIRST WELD PASS, CENTER LINE OF THE WELD, AND THE SECOND WELD PASS (Cont'd)

Specimen 33-5

Survey	Zone	Initial Length (Inches)	Final Length (Inches)	Measured Extension (Inches)	Percent Strain for Each Zone	Percent of Total Increase in Length Across the Weldment (2 Inch Gage Length) Contributed by Each Zone
Overall Measurement	2 Inch Gage Length	2.000	2.124	.124	6.20	100.0
First Weld Pass	Weld Metal	.381	.444	.063	16.5	50.8
	Top HAZ	.058	.064	.006	10.3	4.8
	Bottom HAZ	.050	.053	.003	6.0	2.4
	Base Metal	1.511	1.525	.014	0.93	11.3
						Σ 69.3
Center Line Through Weldment	Weld Metal	.314	.373	.059	18.8	47.6
	Top HAZ	.045	.049	.004	8.9	3.2
	Bottom HAZ	.043	.048	.005	11.6	4.0
	Base Metal	1.597	1.612	.015	0.94	12.1
						Σ 66.9
Second Weld Pass	Weld Metal	.374	.472	.098	26.2	79.1
	Top HAZ	.089	.098	.009	10.1	7.3
	Bottom HAZ	.073	.077	.004	5.5	3.2
	Base Metal	1.464	1.485	.021	1.4	16.9
						Σ 106.5

TABLE III

COMPARISON OF STRAIN MEASUREMENTS IN A 3/4 INCH THICK 2219-T87 ALUMINUM WELDMENT AS DETERMINED BY SURVEYS THROUGH THE FIRST WELD PASS, CENTER LINE OF THE WELD, AND THE SECOND WELD PASS (Cont'd)

Specimen 33-6

Survey	Zone	Initial Length (Inches)	Final Length (Inches)	Measured Extension (Inches)	Percent Strain for Each Zone	Percent of Total Increase in Length Across the Weldment (2 Inch Gage Length) Contributed by Each Zone
Overall Measurement	2 Inch Gage Length	2.000	2.112	.112	5.60	100.0
First Weld Pass	Weld Metal	.403	.466	.063	15.6	56.3
	Top HAZ	.056	.061	.005	8.9	4.5
	Bottom HAZ	.056	.061	.005	8.9	4.5
	Base Metal	1.479	1.493	.014	0.9	12.5
						Σ 77.8
Center Line through Weldment	Weld Metal	.313	.381	.068	21.7	60.7
	Top HAZ	.049	.054	.005	10.2	4.5
	Bottom HAZ	.049	.054	.005	10.2	4.5
	Base Metal	1.562	1.589	.027	1.7	24.1
						Σ 93.8
Second Weld Pass	Weld Metal	.403	.462	.059	14.7	52.7
	Top HAZ	.063	.068	.005	7.9	4.5
	Bottom HAZ	.076	.081	.005	6.6	4.5
	Base Metal	1.457	1.477	.020	1.4	17.8
						Σ 79.5

TABLE IV

MECHANICAL PROPERTIES OF SPECIMENS FROM FIRST AND SECOND PASS OF 3/4 INCH THICK 2219-T87 ALUMINUM WELDMENTS USED IN DUCTILITY MEASUREMENTS[1]

Specimen	Yield Strength (0.2% offset) psi	Ultimate Tensile Strength psi	Percent Elongation (in 2 inches)
27-X 1st Pass.	24,600	41,700	5.8
27-X 2nd Pass.	22,150	39,900	6.3
27-Y 1st Pass.	22,500	39,300	5.3
27-Y 2nd Pass.	22,400	39,500	5.0
27-Z 1st Pass.	21,900	39,150	4.0
27-Z 2nd Pass.	22,200	39,850	6.0
Average Value 1st Pass.	23,000	40,050	5.0
Average Value 2nd Pass.	22,250	39,730	5.5

[1] Horizontal square butt weld one pass from either side.

TABLE V

SUMMARY OF CALCULATED STRAIN IN WELD METAL, HAZ AND BASE METAL OF TENSILE SPECIMENS FABRICATED FROM THE FIRST WELD PASS AND SECOND WELD PASS OF A 3/4 INCH THICK 2219-T-87 ALUMINUM WELDMENT

Specimen	Percent Strain In Weld Metal[1]	Percent Strain In Heat Affected Zone[1]	Percent Strain In Base Metal[1]	Percent Elongation Over 2 Inch Gage Length
27-X 1st Pass	32.0	8.5	0.13	5.8
27-Y 1st Pass	26.1	4.4	0.20	5.3
27-Z 1st Pass	19.4	5.3	0.00	4.0
Average	25.9	6.1	0.11	5.1
Percent of average Elongation contributed by each zone	90.8	2.(3.3)= 6.6	1.6	100.0
27-X 2nd Pass	31.0	6.0	0.26	6.3
27-Y 2nd Pass	23.7	6.8	0.07	5.0
27-Z 2nd Pass	28.9	6.0	0.00	6.0
Average	27.9	6.3	0.11	5.8
Percent of total extension across welded joint (2" gage length) contributed by each zone	89.7	2.(3.0)= 6.0	1.7	100.0

[1] Percent strain= $\frac{\Delta \ell}{\text{initial length}} \times 100$

TABLE VI

CALCULATED PERCENT STRAIN IN INDIVIDUAL WELD ZONES IN A WELD JOINT AS DETERMINED BY SURVEYS OF TENSILE SPECIMENS FABRICATED FROM THE FIRST PASS OF A 3/4 INCH THICK 2219-T87 ALUMINUM WELDMENT

Specimen	Zone	Initial Length (Inches)	Final Length (Inches)	Measured Extension (Inches)	Percentage Strain for Each Zone[1]	Percentage Elongation Over 2 Inch Gage Length
27-X 1st Pass	2 Inch Gage Length	2.00	2.116	0.116	5.8	100.0
	Weld	.294	.389	0.095	32.0	81.7
	Top HAZ	.059	.065	.006	10.2	5.2
	Bottom HAZ	.045	.048	.003	6.7	2.6
	Base Metal	1.601	1.603	.002	0.13	1.7
						Σ 91.2
27-Y 1st Pass	2 Inch Gage Length	2.00	2.106	.106	5.3	100.0
	Weld	.399	.503	.104	26.1	98.0
	Top HAZ	.072	.075	.003	4.2	2.7
	Bottom HAZ	.044	.046	.002	4.5	1.9
	Base Metal	1.484	1.487	.003	.20	2.7
						Σ 105.3
27-Z 1st Pass	2 Inch Gage Length	2.00	2.080	.080	4.0	100.0
	Weld	.407	.486	.079	19.4	98.8
	Top HAZ	.058	.061	.003	5.2	3.7
	Bottom HAZ	.052	.055	.003	5.3	0
	Base Metal	1.482	1.482	.000	0	Σ 105.9

[1] Percent strain = $\dfrac{\Delta \ell}{\text{initial length}} \times 100$

TABLE VI

CALCULATED PERCENT STRAIN IN INDIVIDUAL WELD ZONES IN A WELD JOINT AS DETERMINED BY SURVEYS OF TENSILE SPECIMENS FABRICATED FROM THE SECOND PASS OF A 3/4 INCH THICK 2219-T87 ALUMINUM WELDMENT (Cont'd)

Specimen	Zone	Initial Length (Inches)	Final Length (Inches)	Measured Extension (Inches)	Percentage Strain for Each Zone[1]	Percentage of Total Increase in Length Across the Weldment (2 Inch Gage Length) Contributed by Each Zone
27-X 2nd Pass	2 Inch Gage Length	2.00	2.126	.126	6.3	100.0
	Weld	.345	.452	.107	31.0	84.8
	Top HAZ	.066	.070	.004	6.1	3.2
	Bottom HAZ	.052	.055	.003	5.8	4.6
	Base Metal	1.536	1.540	.004	.26	3.2
						Σ 95.8
27-Y 2nd Pass	2 Inch Gage Length	2.00	2.100	.100	5.0	100.0
	Weld	.392	.485	.093	23.7	93.0
	Top HAZ	.062	.066	.004	6.4	4.0
	Bottom HAZ	.055	.059	.004	7.3	4.0
	Base Metal	1.490	1.491	.001	.07	1.0
						Σ102.0
27-Z 2nd Pass	2 Inch Gage Length	2.00	2.120	.120	6.0	100.0
	Weld	.363	.468	.105	28.9	87.5
	Top HAZ	.052	.056	.004	7.7	3.3
	Bottom HAZ	.048	.050	.002	4.2	1.7
	Base Metal	1.536	1.536	.000	0.00	0.00
						Σ 92.5

[1] Percent strain = $\frac{\Delta \ell}{\text{initial length}} \times 100$

ILLUSTRATIONS

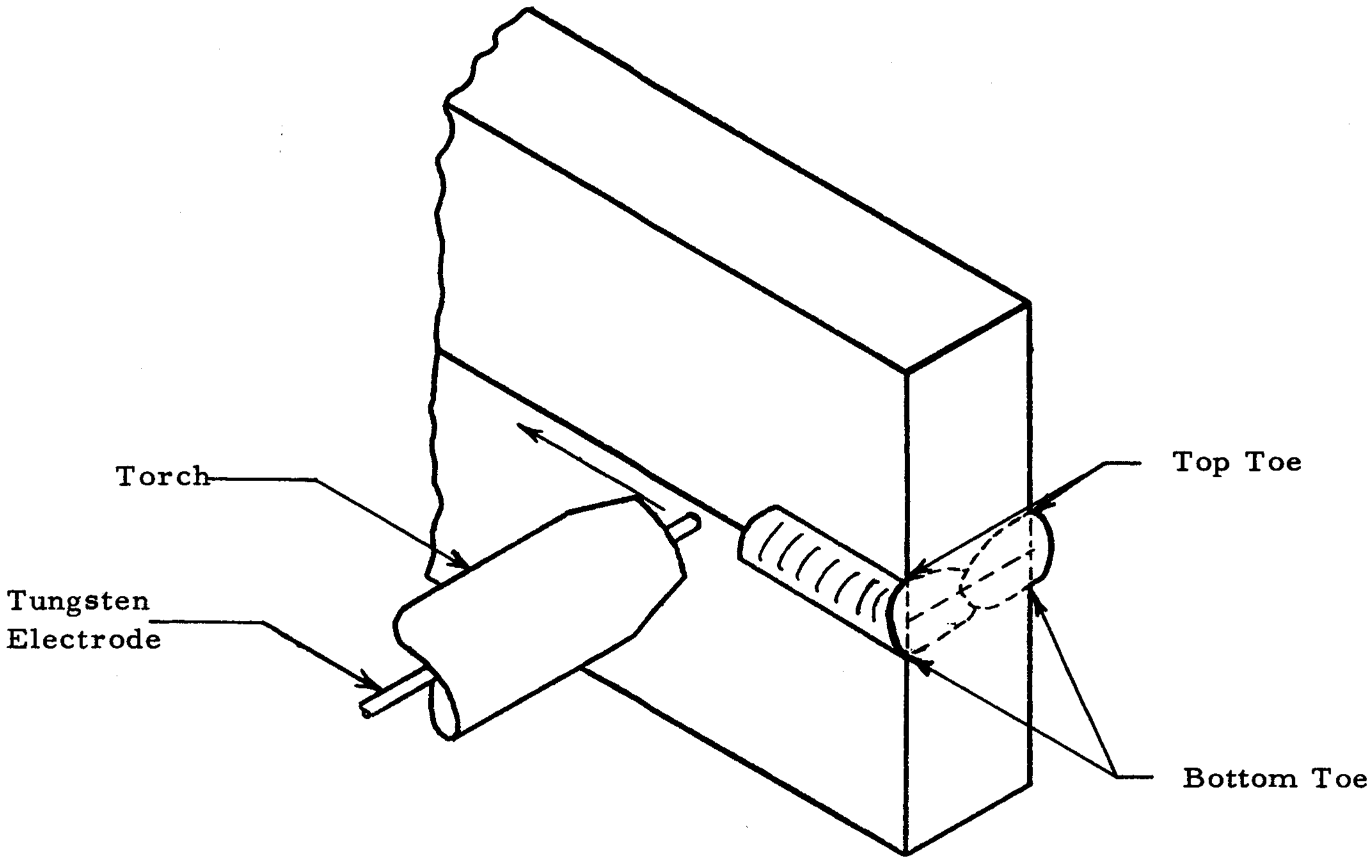
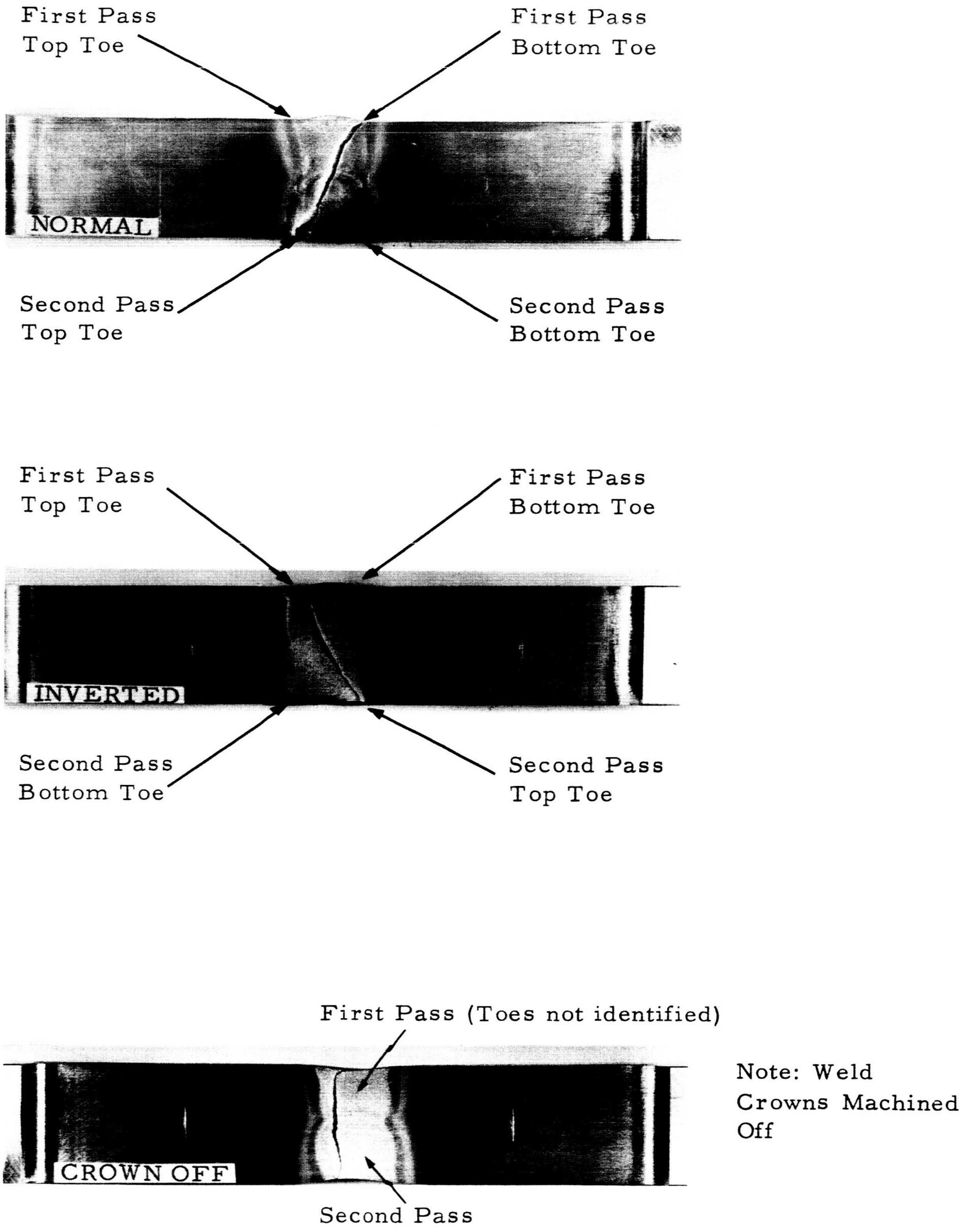


FIGURE 1. HORIZONTAL WELDING POSITION. NOTE THAT LIKE TOES ARE OPPOSITE EACH OTHER WITH REFERENCE TO PANEL THICKNESS. "NORMAL PANEL".



Etchant - Keller's 1X

FIGURE 2. MODE OF FRACTURE IN THREE DIFFERENT TYPES OF TENSILE TEST SPECIMENS OF RECTANGULAR CROSS SECTION

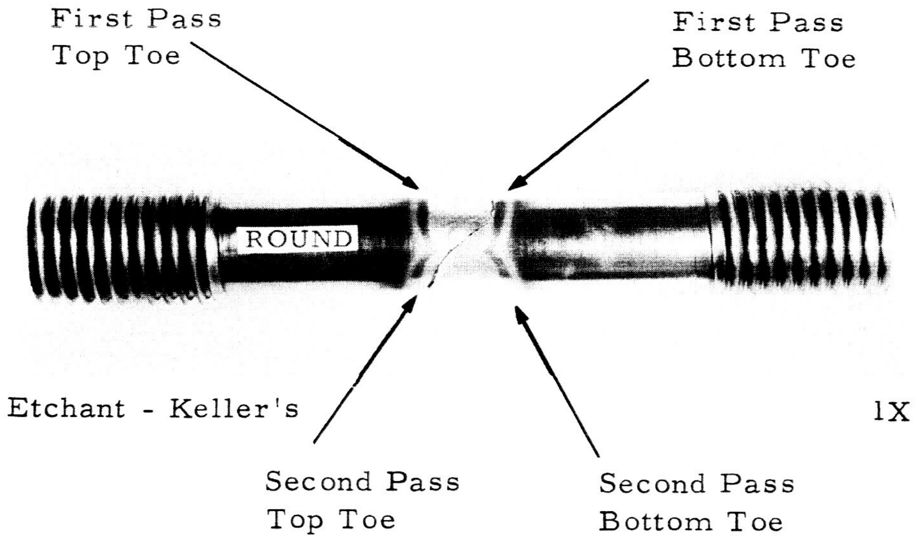


FIGURE 3. FRACTURE PATH IN A ROUND TENSILE SPECIMEN

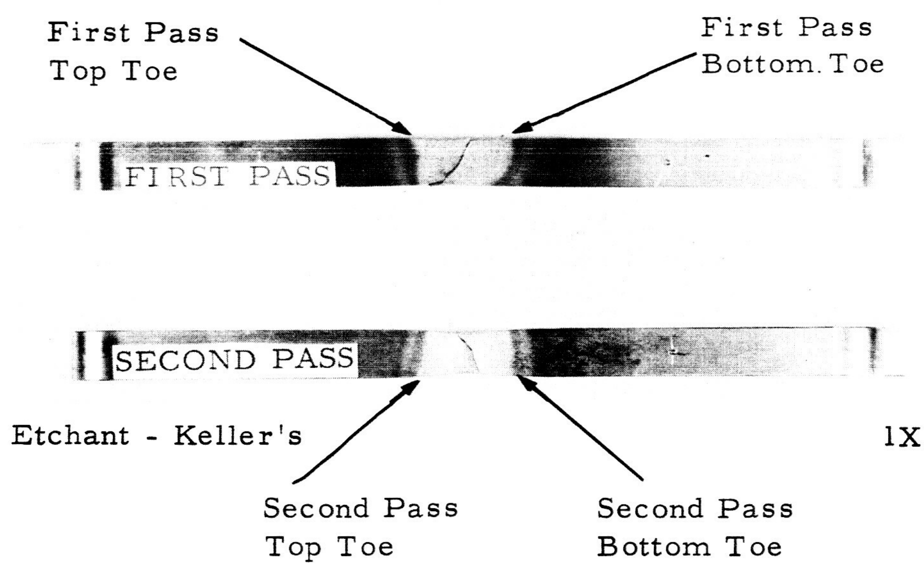


FIGURE 4. THE FRACTURE PATH IN ADJOINING FIRST AND SECOND WELD PASSES WHEN TESTED AS SEPARATE TENSILE SPECIMENS

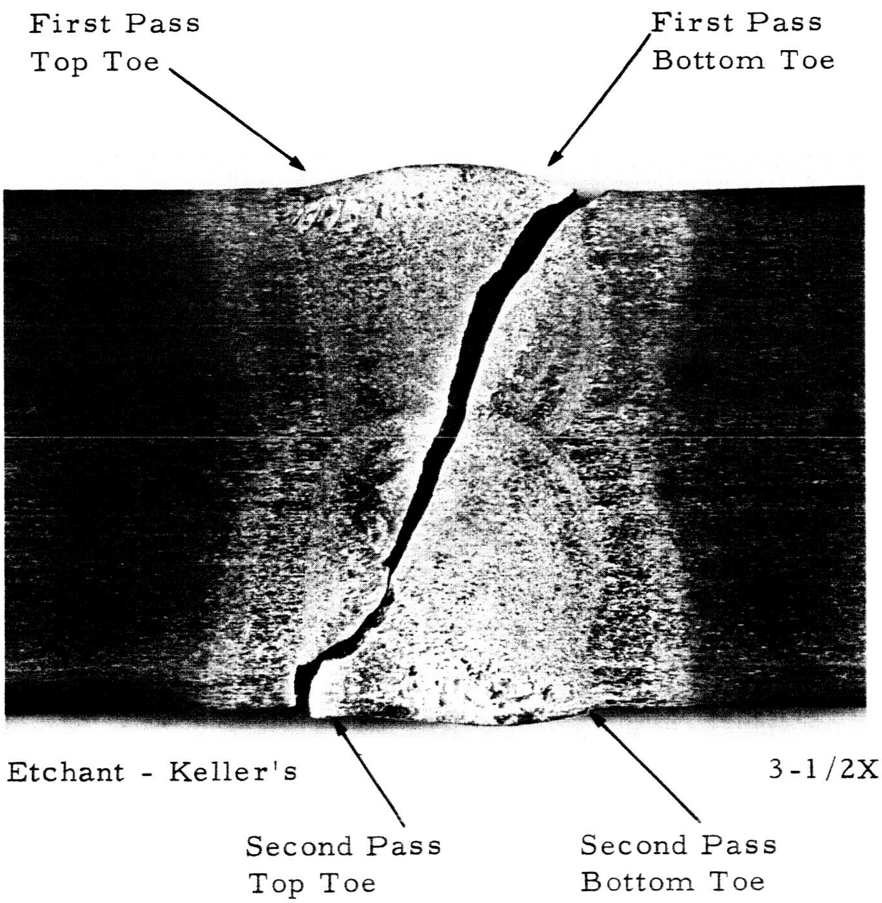
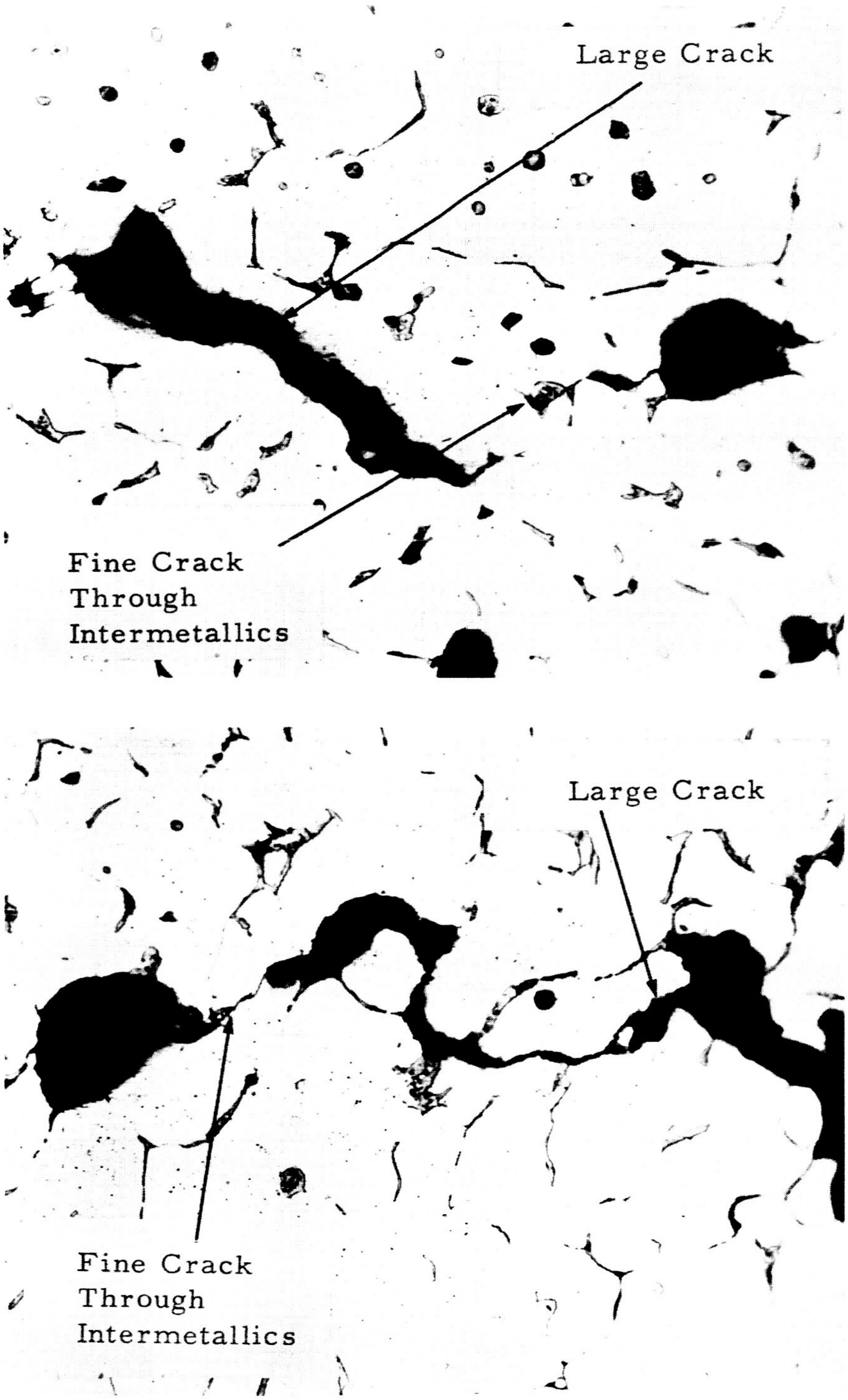
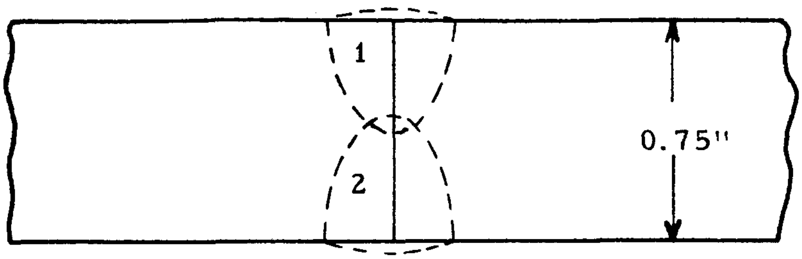


FIGURE 5. APPEARANCE OF A GAP IN THE FRACTURE PATH ON BUTTING TOGETHER A BROKEN TENSILE SPECIMEN



Etchant - Keller's 1000X

FIGURE 6. CRACKS IN WELD DEPOSIT OF UNIAXIAL TENSILE SPECIMEN. NOTE THAT THE CRACKS FOLLOW THE PATH OF INTERMETALLIC CONSTITUENTS.



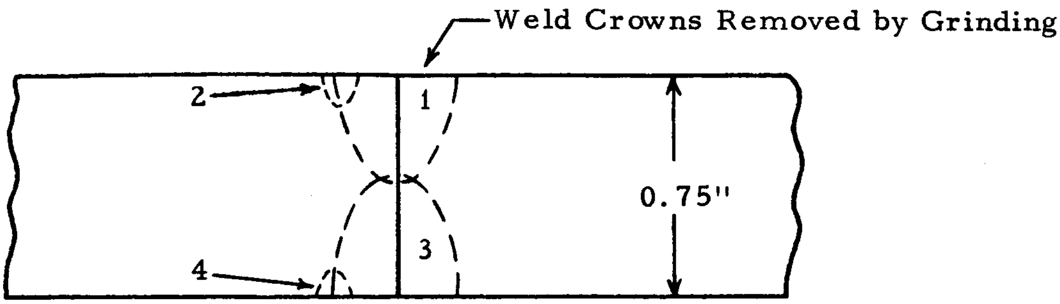
Joint Preparation and Welding Sequence

Welding Parameters*

Pass No.	Amps	Volts	Cold Wire Diameter (inches)	Cold Wire Feed Rate (ipm)	Travel Speed (ipm)
1	386	11.5	3/64	9	5
2	386	11.5	3/64	9	5

*All welding carried out in the horizontal position using a 5/32 inch diameter thoriated tungsten electrode and 60 cfh (Helium) gas flow rate.

FIGURE 7. JOINT DESIGN AND WELDING PARAMETERS USED IN THE PREPARATION OF HYDRAULIC BULGE TEST PANELS NO. 41 AND 42



Joint Preparation and Welding Sequence

Welding Parameters*

Pass No.	Amps	Volts	Cold Wire Diameter (inches)	Cold Wire Feed Rate (ipm)	Travel Speed (ipm)
1	380	11.5	3/64	9	5
2	244	11.5	3/64	9	5
3	366	11.5	3/64	9	5
4	244	11.5	3/64	9	5

*All passes made in the horizontal position using a 5/32 inch diameter thoriated tungsten electrode and 60 cfh (Helium) gas flow rate.

FIGURE 8. JOINT DESIGN AND WELDING PARAMETERS USED IN THE PREPARATION OF HYDRAULIC BULGE TEST PANEL NO. 46

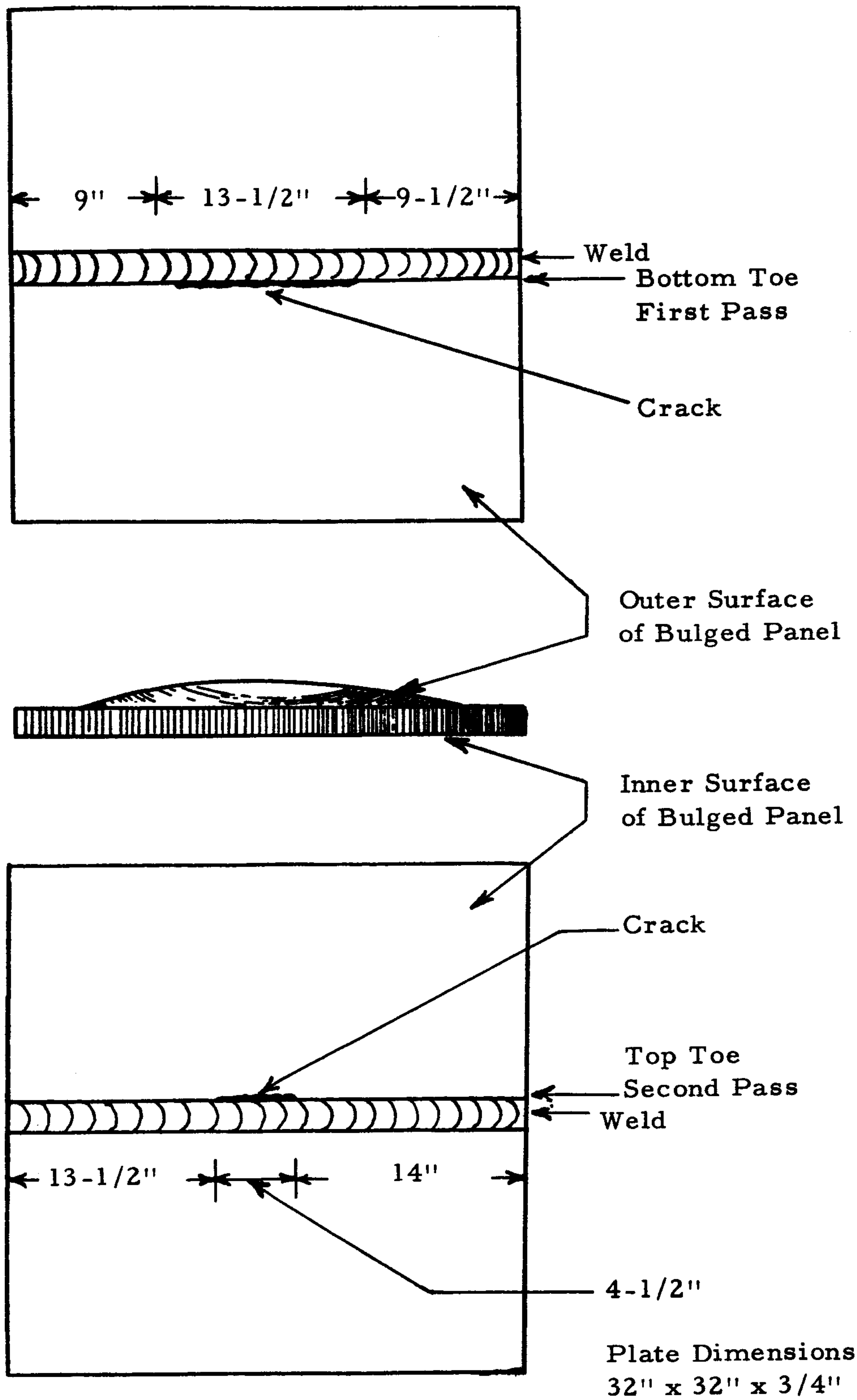


FIGURE 9. LOCATION AND MEASUREMENTS OF SURFACE CRACKS IN SINGLE BUTT WELD PANEL NO. 41 AFTER HYDRAULIC BULGE TEST

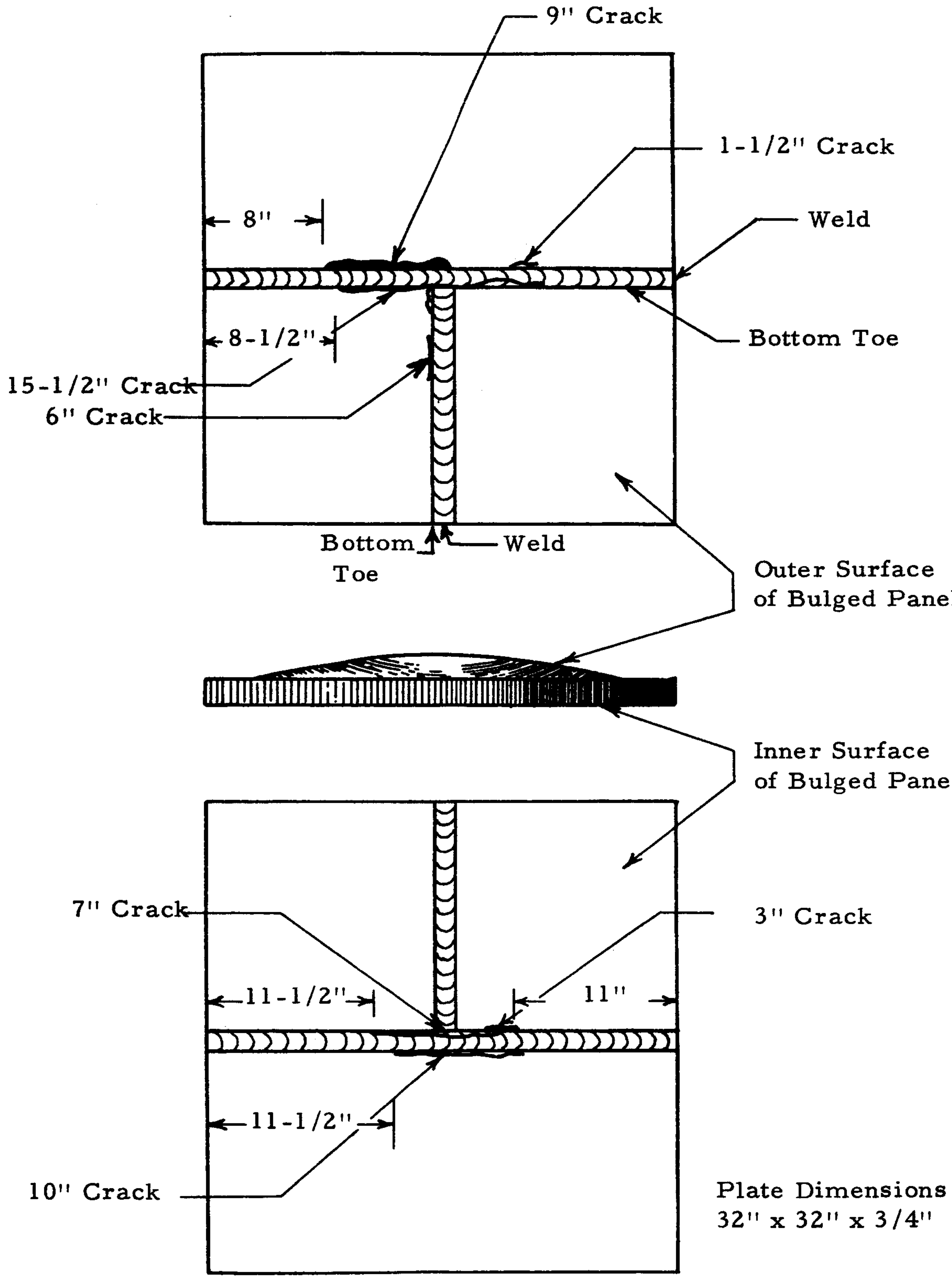


FIGURE 10. LOCATION AND MEASUREMENTS OF SURFACE CRACKS IN "TEE" WELD (PANEL NO. 42) AFTER HYDRAULIC BULGE TEST

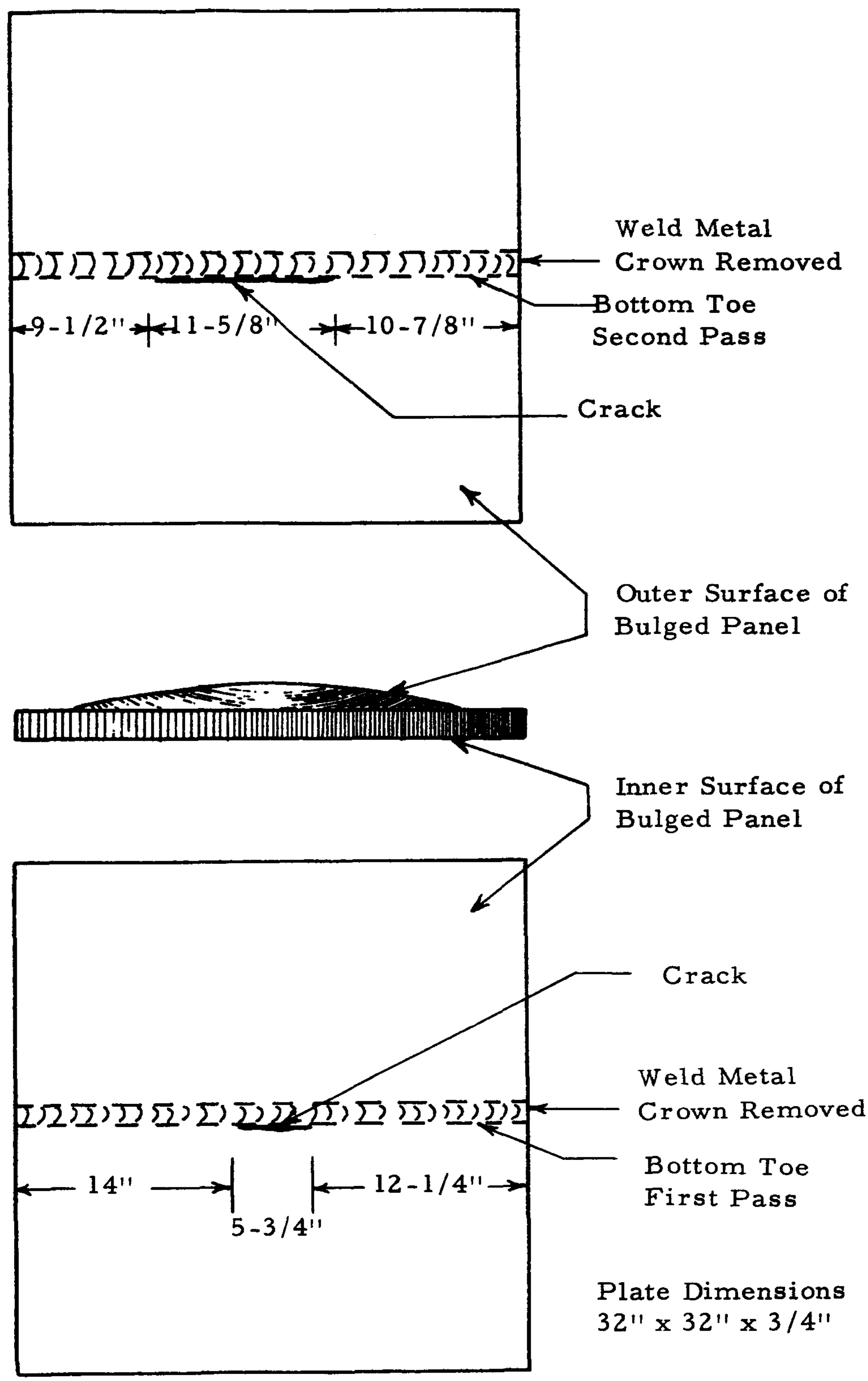


FIGURE 11. LOCATION AND MEASUREMENTS OF SURFACE CRACKS IN SINGLE BUTT WELD PANEL NO. 46 AFTER HYDRAULIC BULGE TEST

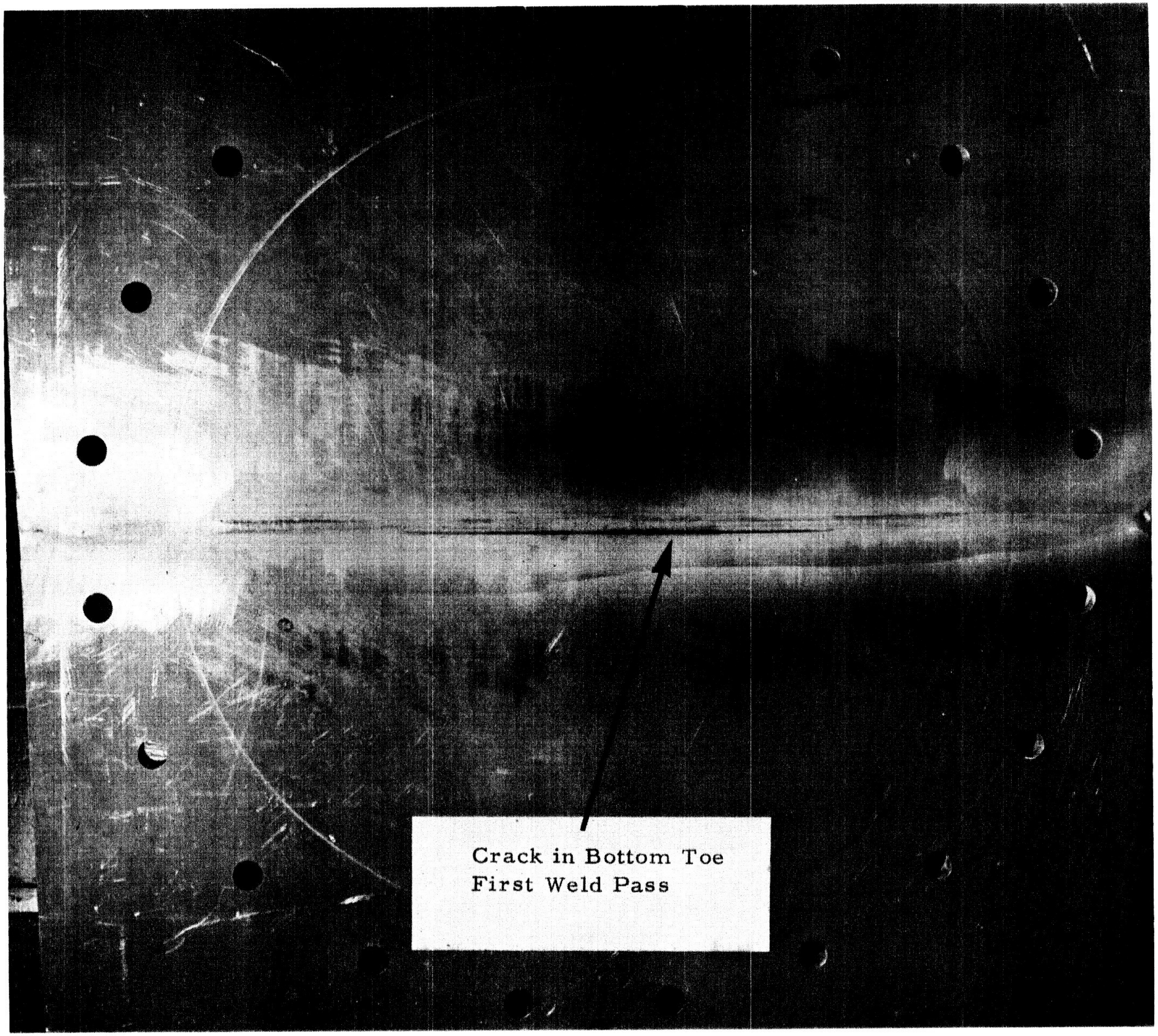


FIGURE 12. CRACK ON OUTER SURFACE OF PANEL NO. 41

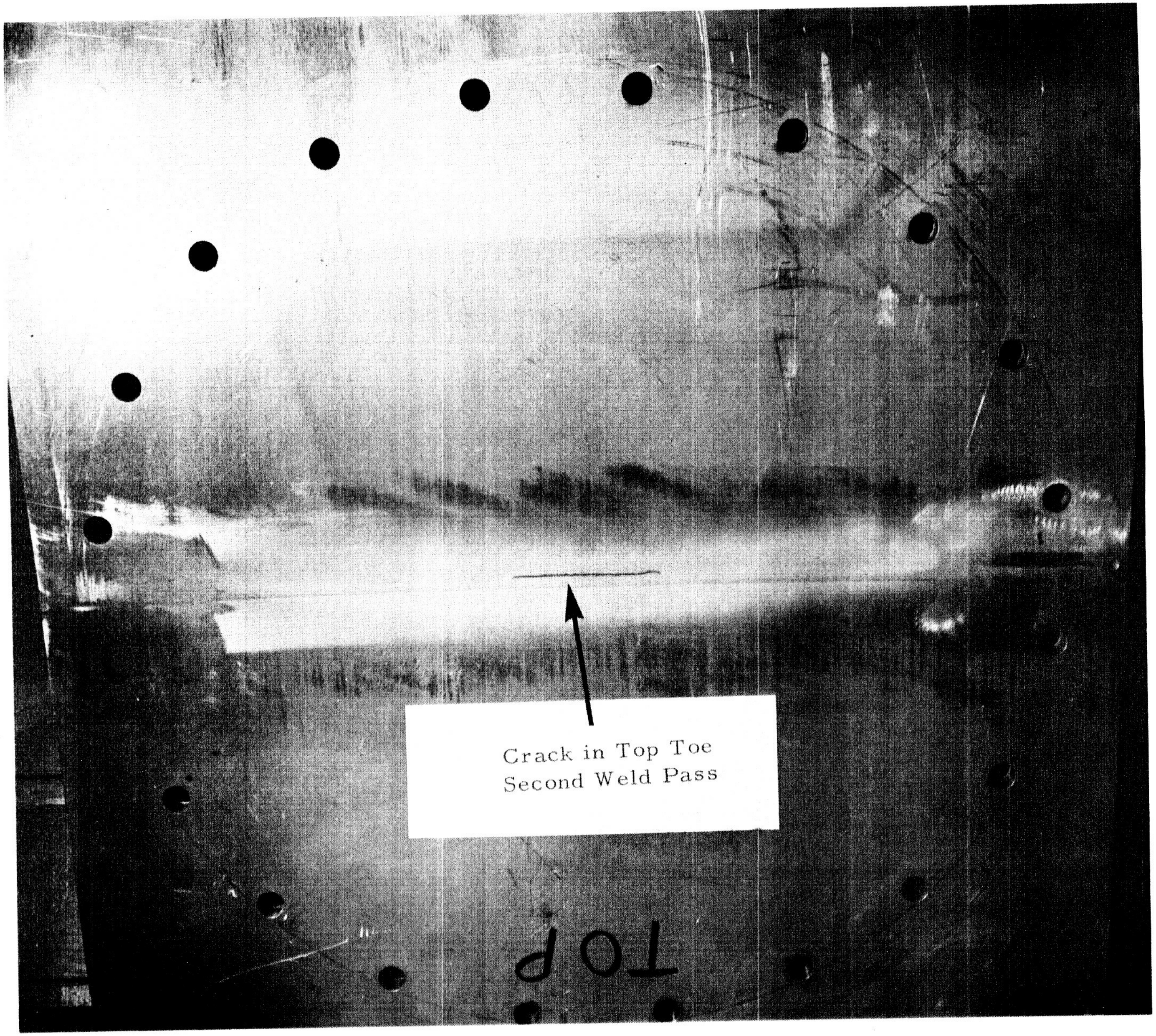


FIGURE 13. CRACK ON INNER SURFACE OF PANEL NO. 41

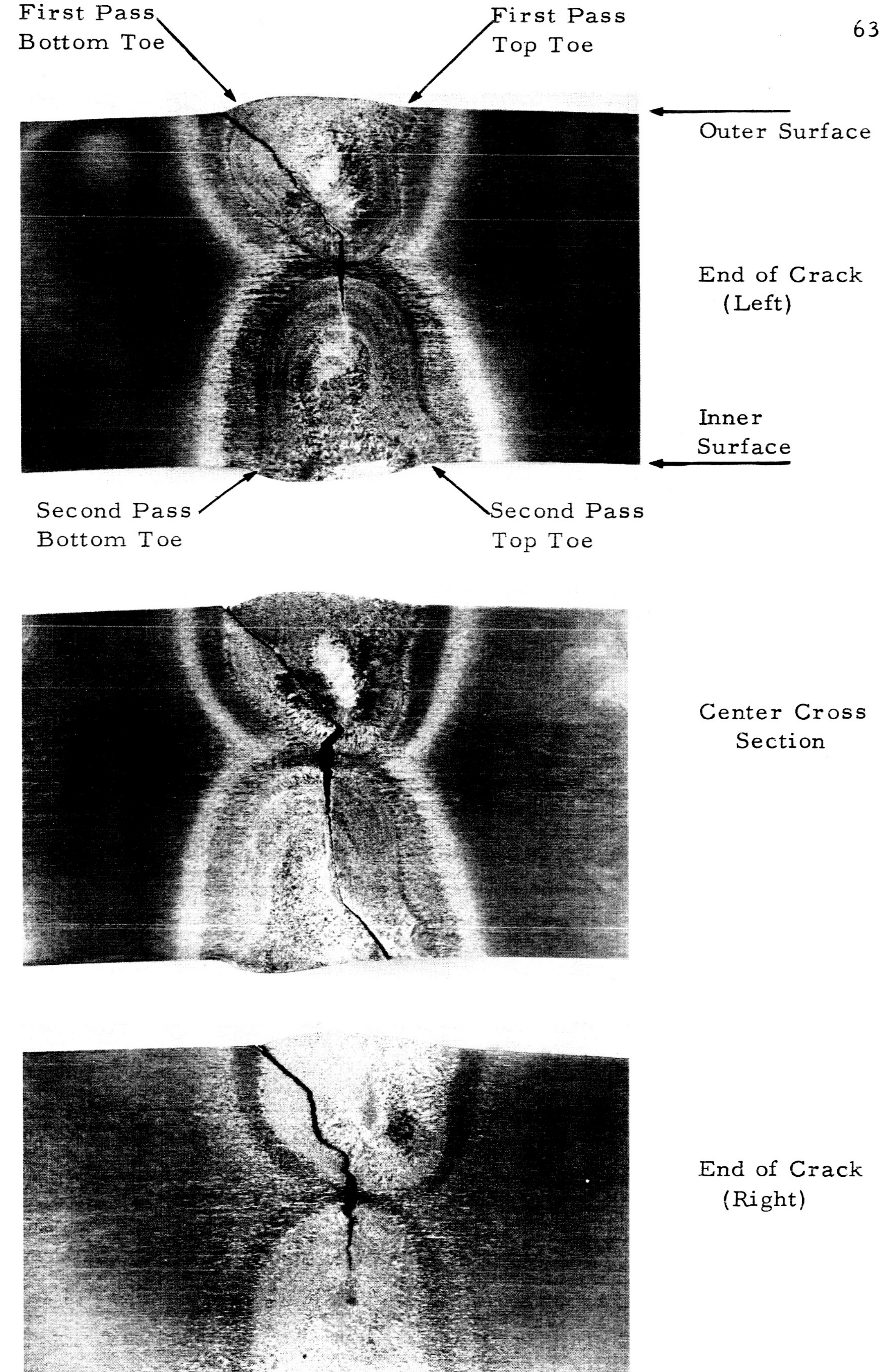


FIGURE 14. CROSS SECTIONS THROUGH CENTER AND ENDS OF RUPTURE IN SQUARE BUTT WELDED HYDRAULICALLY BULGED PANEL NO. 41

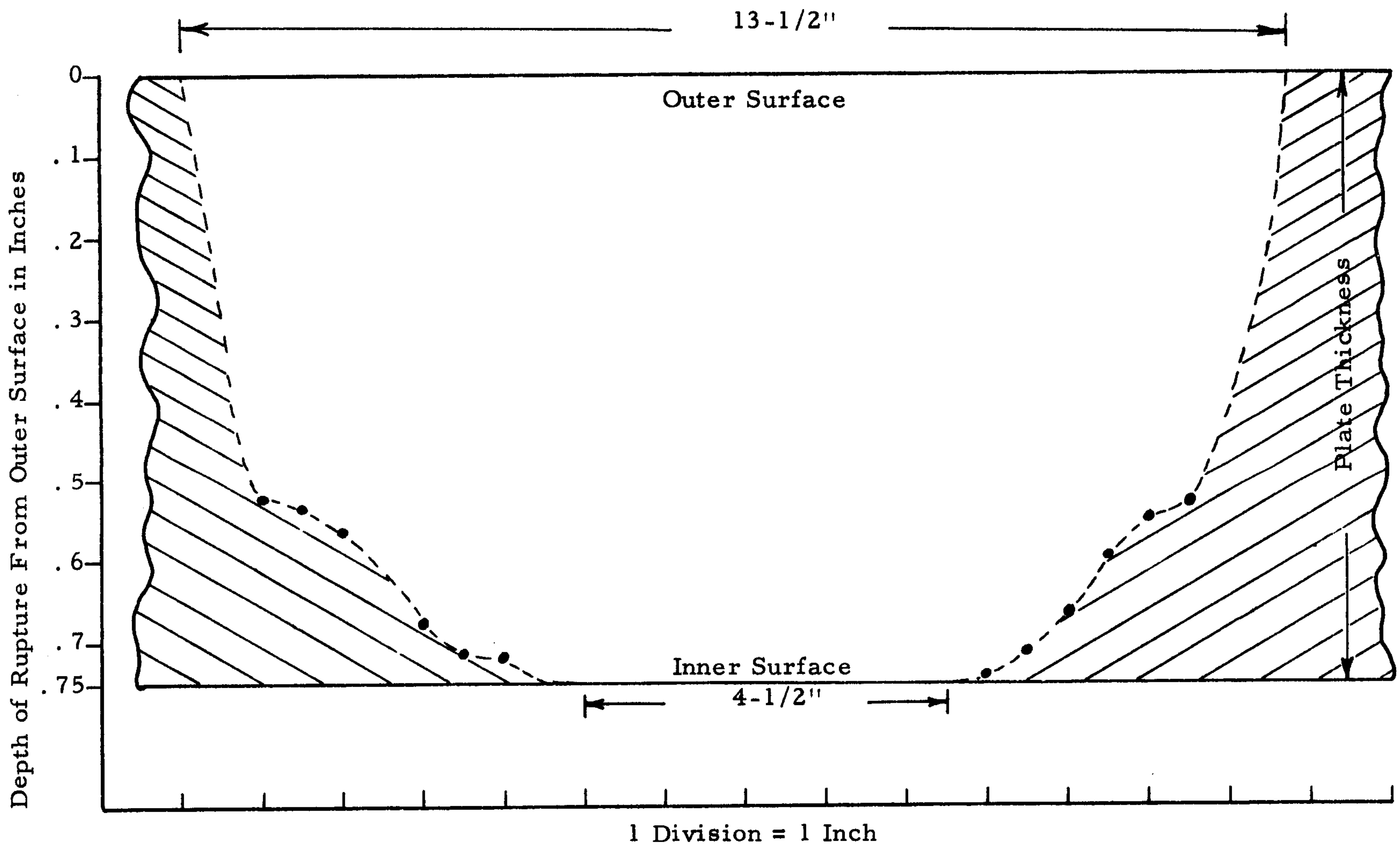
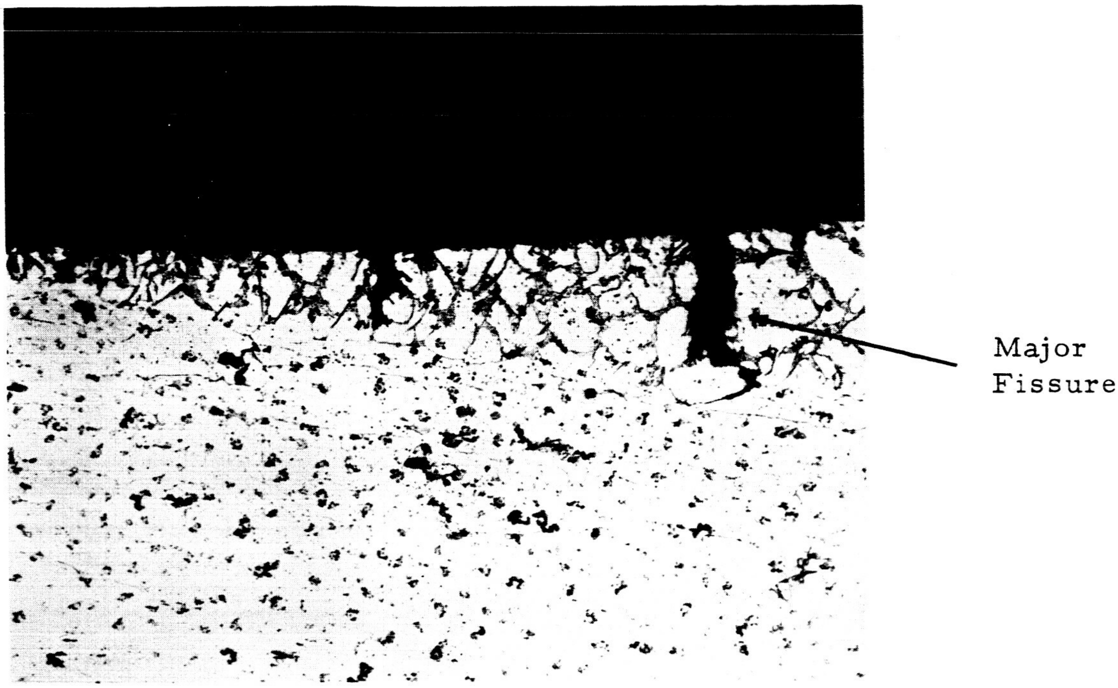
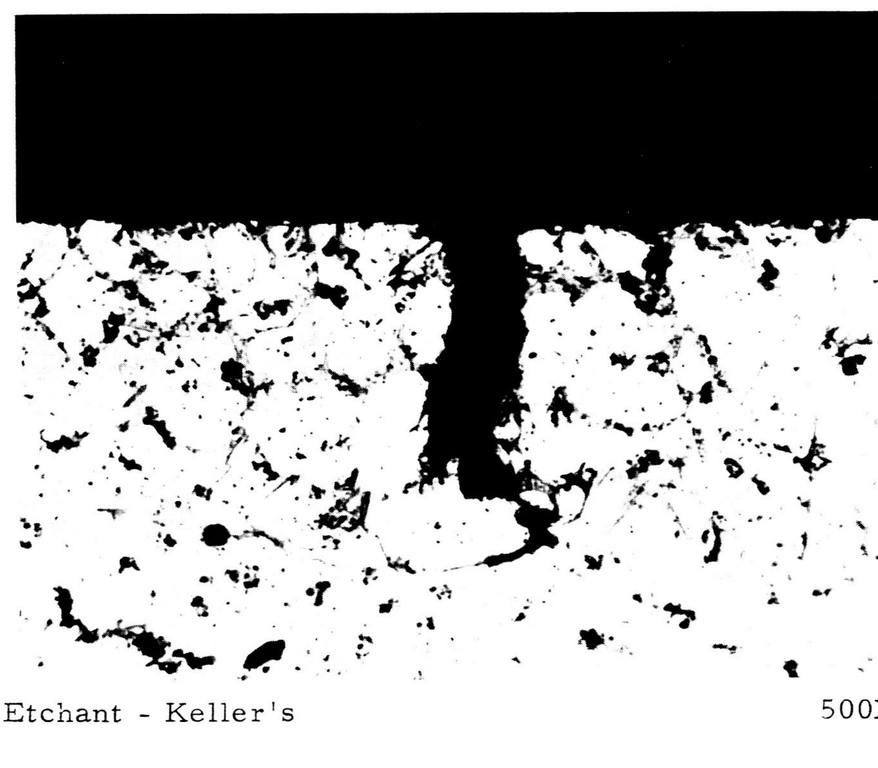


FIGURE 15. PROFILE OF RUPTURE PRODUCED BY HYDRAULICALLY BULGE TESTING THE SINGLE BUTT WELD PANEL NO. 41



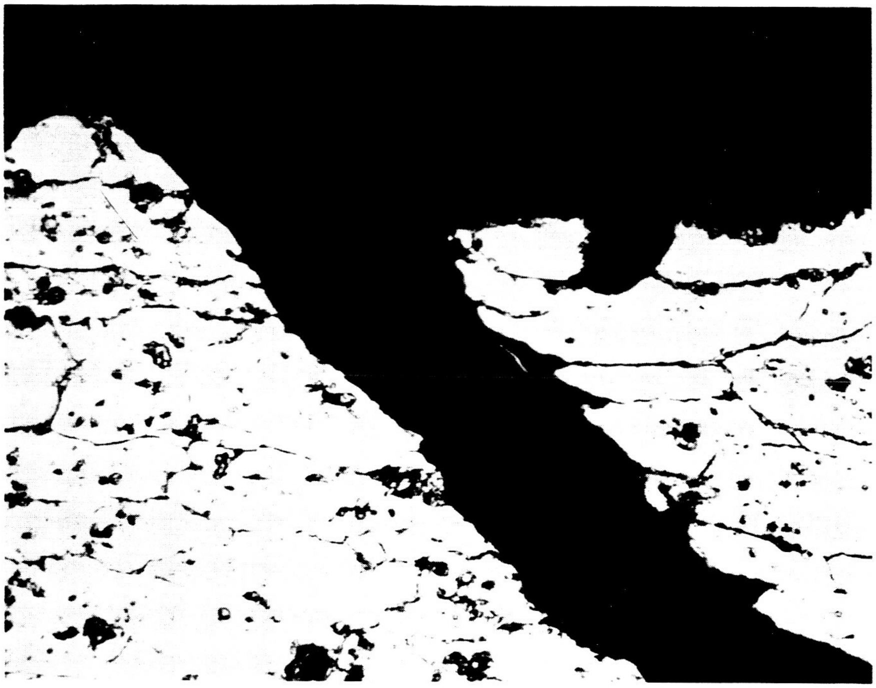
Etchant - Keller's 250X

FIGURE 16. CROSS SECTION OF ONE END OF THE SURFACE CRACK IN THE HYDRAULICALLY BULGED SQUARE BUTT PANEL



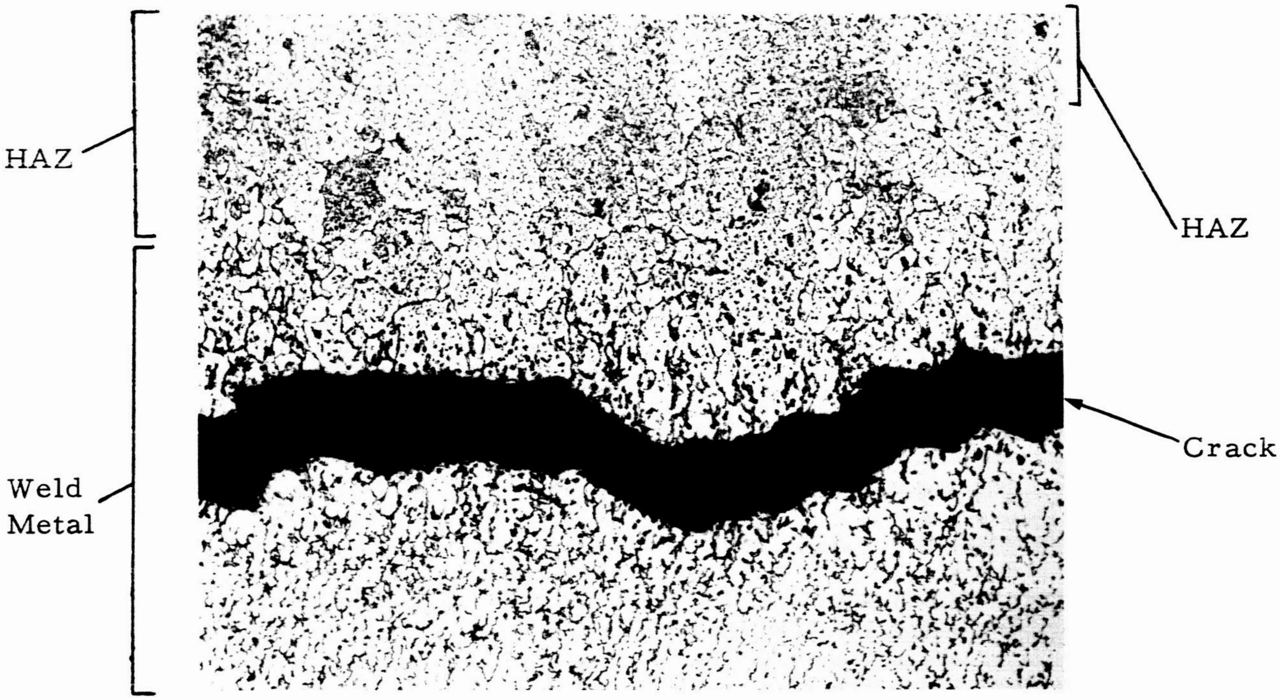
Etchant - Keller's 500X

FIGURE 17. RELATIONSHIP BETWEEN PROPAGATION OF MAJOR FISSURES AND INTERMETALLIC CONSTITUENTS PRESENT



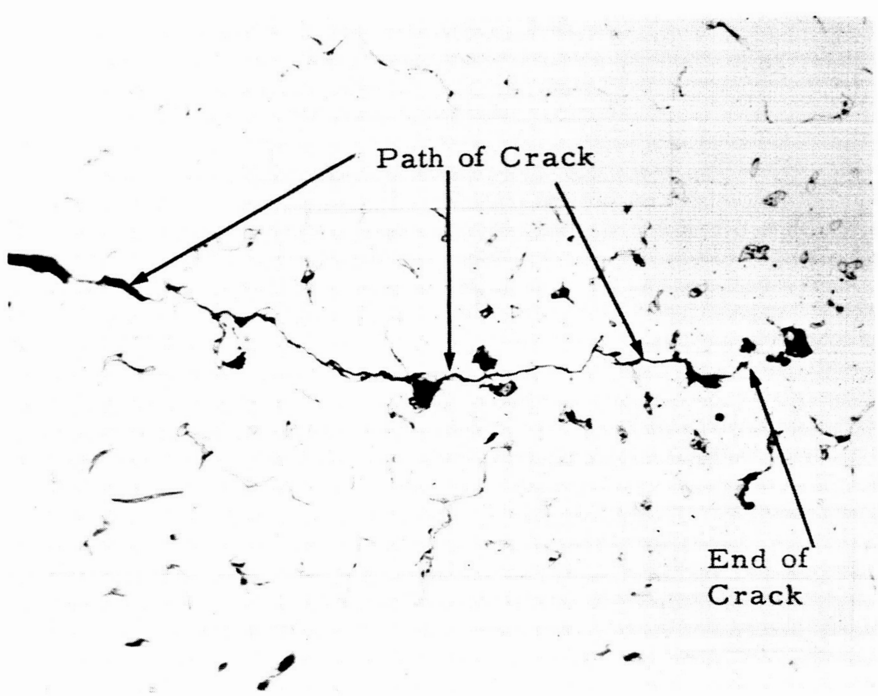
Etchant - Keller's 500X

FIGURE 18. CROSS SECTION OF RUPTURE AT TOP OF OUTER SURFACE OF PANEL 41



Etchant - Keller's 100X

FIGURE 19. VIEW OF RUPTURE AS SEEN LOOKING DOWN ON OUTER SURFACE OF BULGED PANEL. THE CRACK RUNS IN WELD METAL VERY CLOSE TO HAZ-WELD METAL FUSION LINE. (TOE OF WELD)



Etchant - Keller's 1000X

FIGURE 20. PROGRESS OF A CRACK THROUGH WELD METAL PRODUCED BY BIAXIAL TESTING

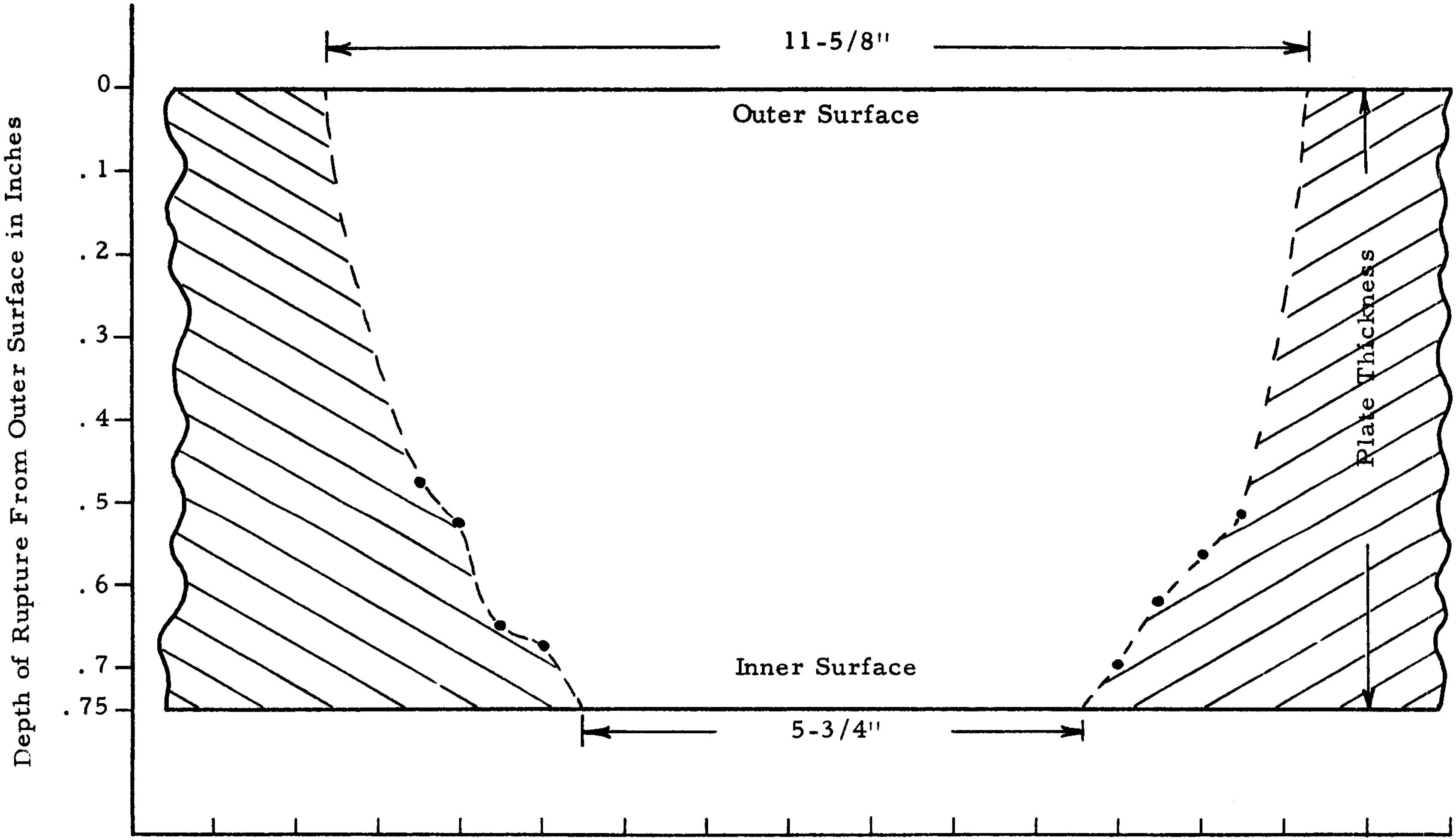
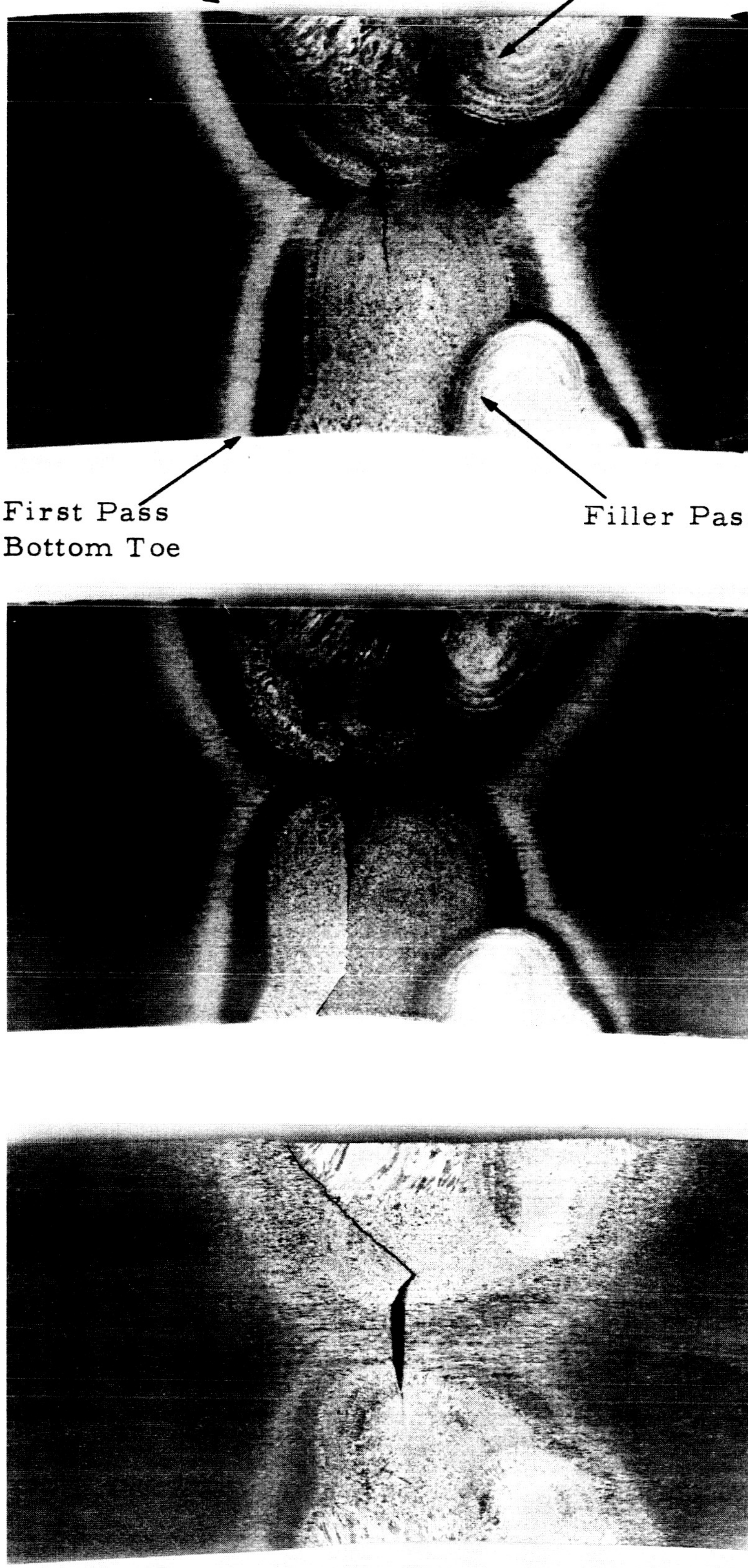


FIGURE 21. PROFILE OF RUPTURE PRODUCED BY HYDRAULICALLY BULGE TESTING THE SINGLE BUTT WELDED PANEL WITH FILLER WELD PASSES. WELD OF CROWNS HAD BEEN GROUND OFF.



Etchant - Keller's 3X

FIGURE 22. CROSS SECTIONS THROUGH CENTER AND ENDS OF RUPTURE IN SQUARE BUTT AND FILLER WELDED (CROWNS GROUND OFF) HYDRAULICALLY BULGED PANEL NO. 46

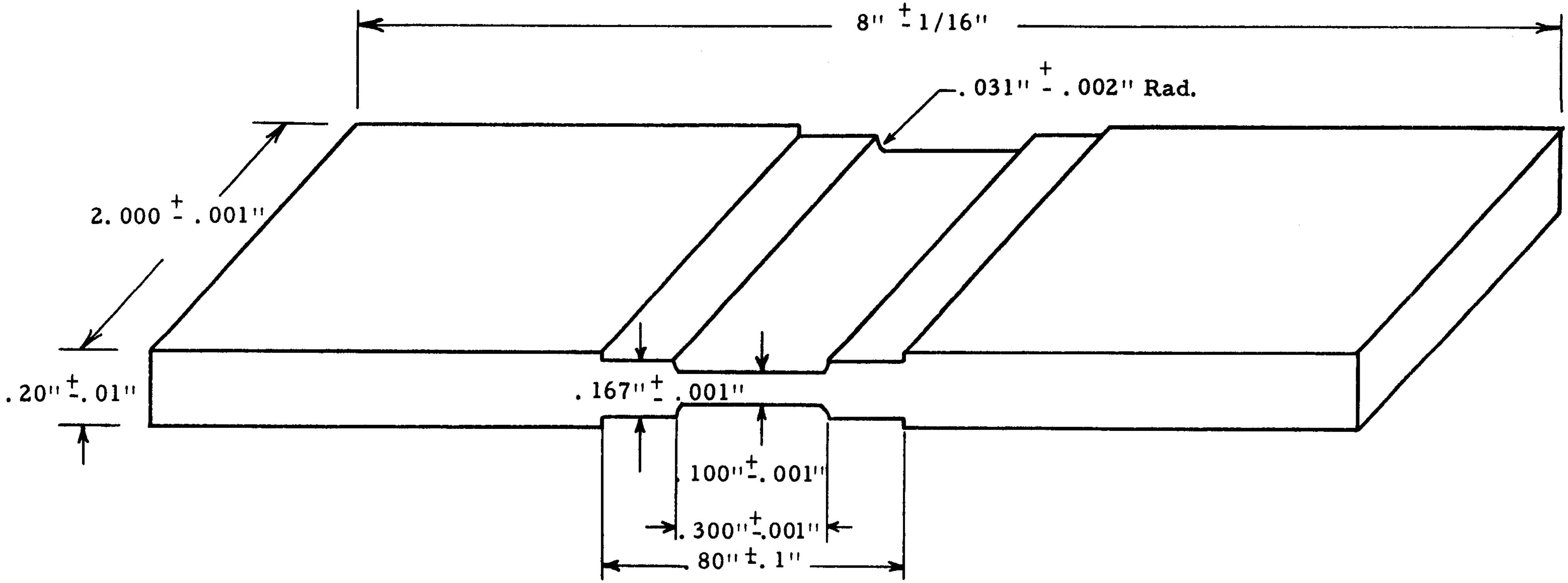


FIGURE 23. BIAXIAL TEST SPECIMEN

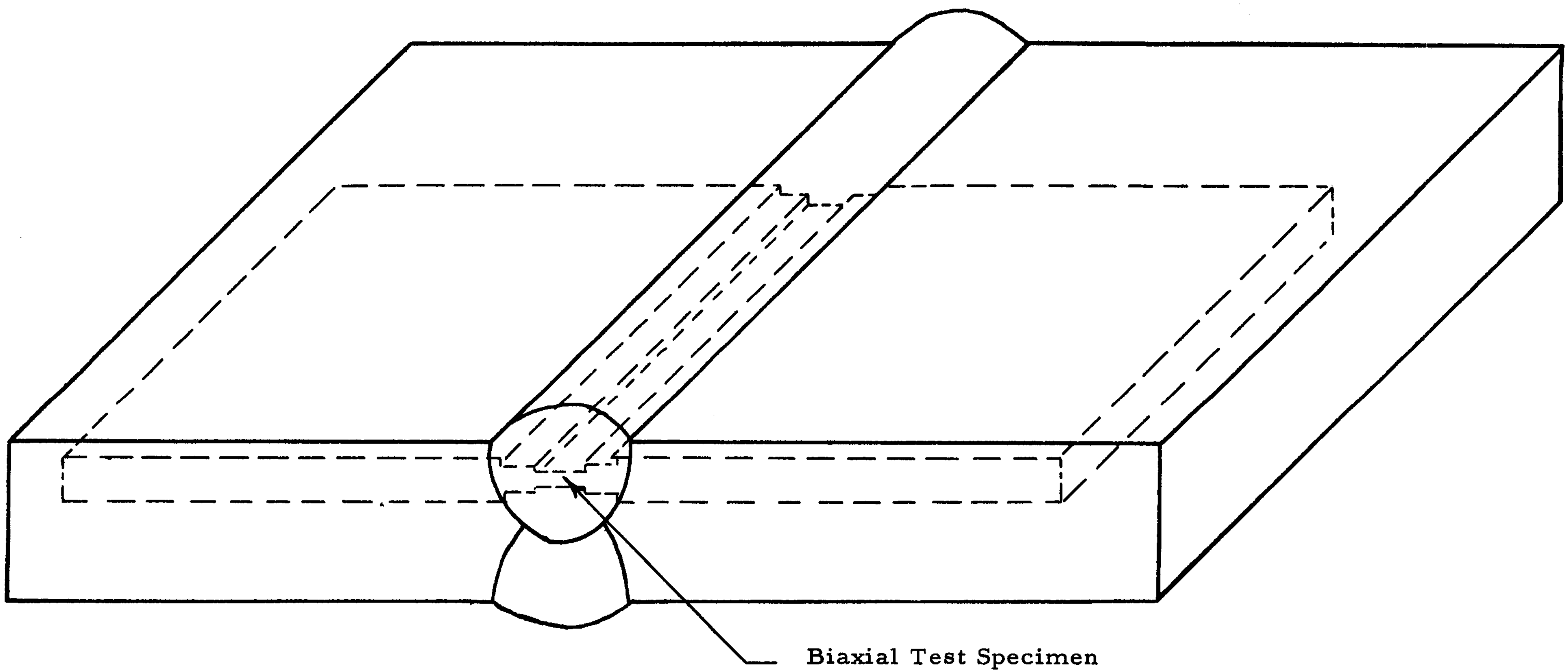


FIGURE 24. LOCATION FROM WHICH BIAXIAL TEST SPECIMENS WERE MACHINED FROM 3/4 INCH THICK, 2219-T87 ALUMINUM WELDED PANELS

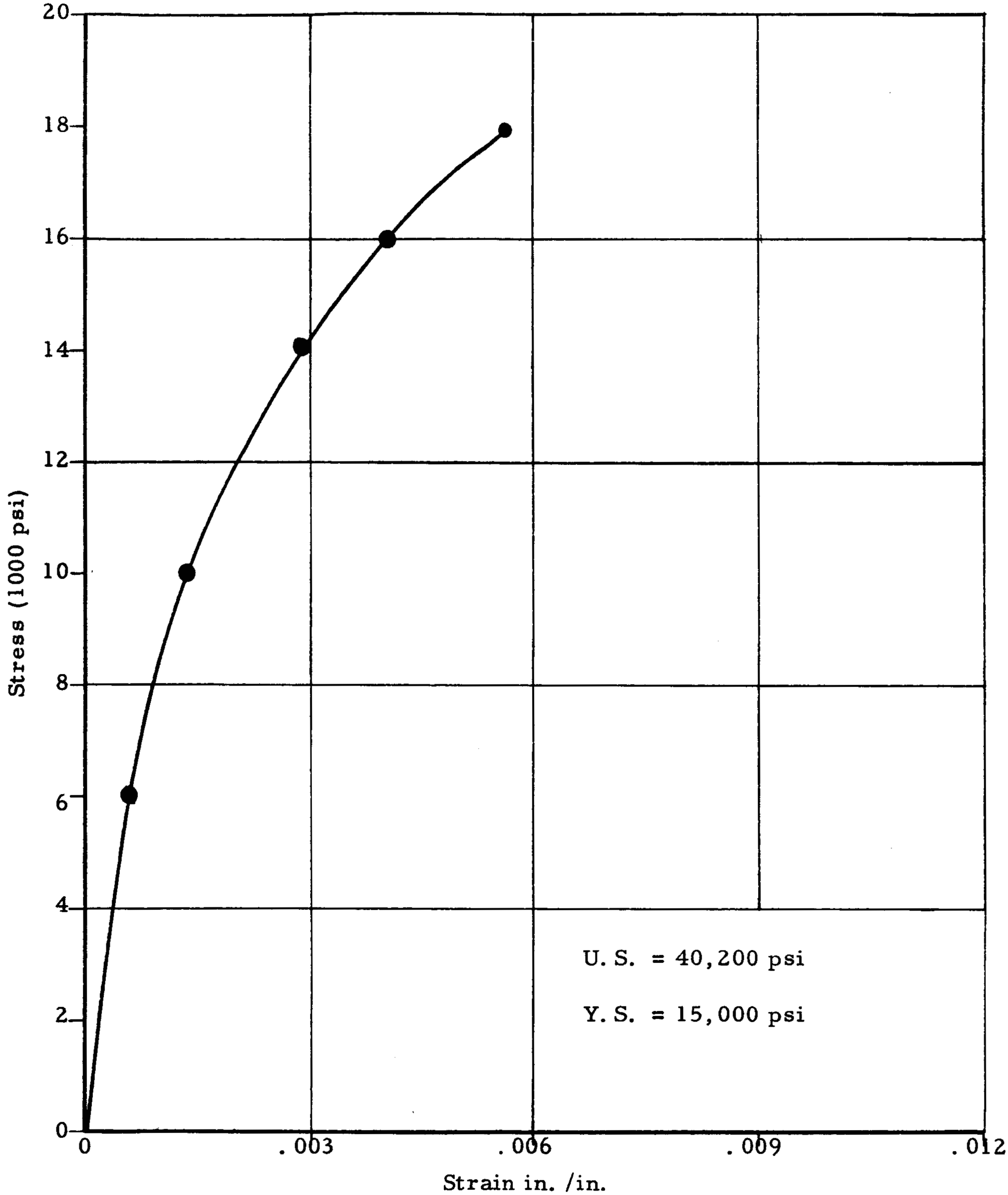


FIGURE 25. STRESS-STRAIN CURVE OF MAJOR STRESSED AXIS OF BIAXIAL TENSILE TEST, 2219-T87 ALUMINUM ALLOY WELDMENT. SPECIMEN NO. B33-1

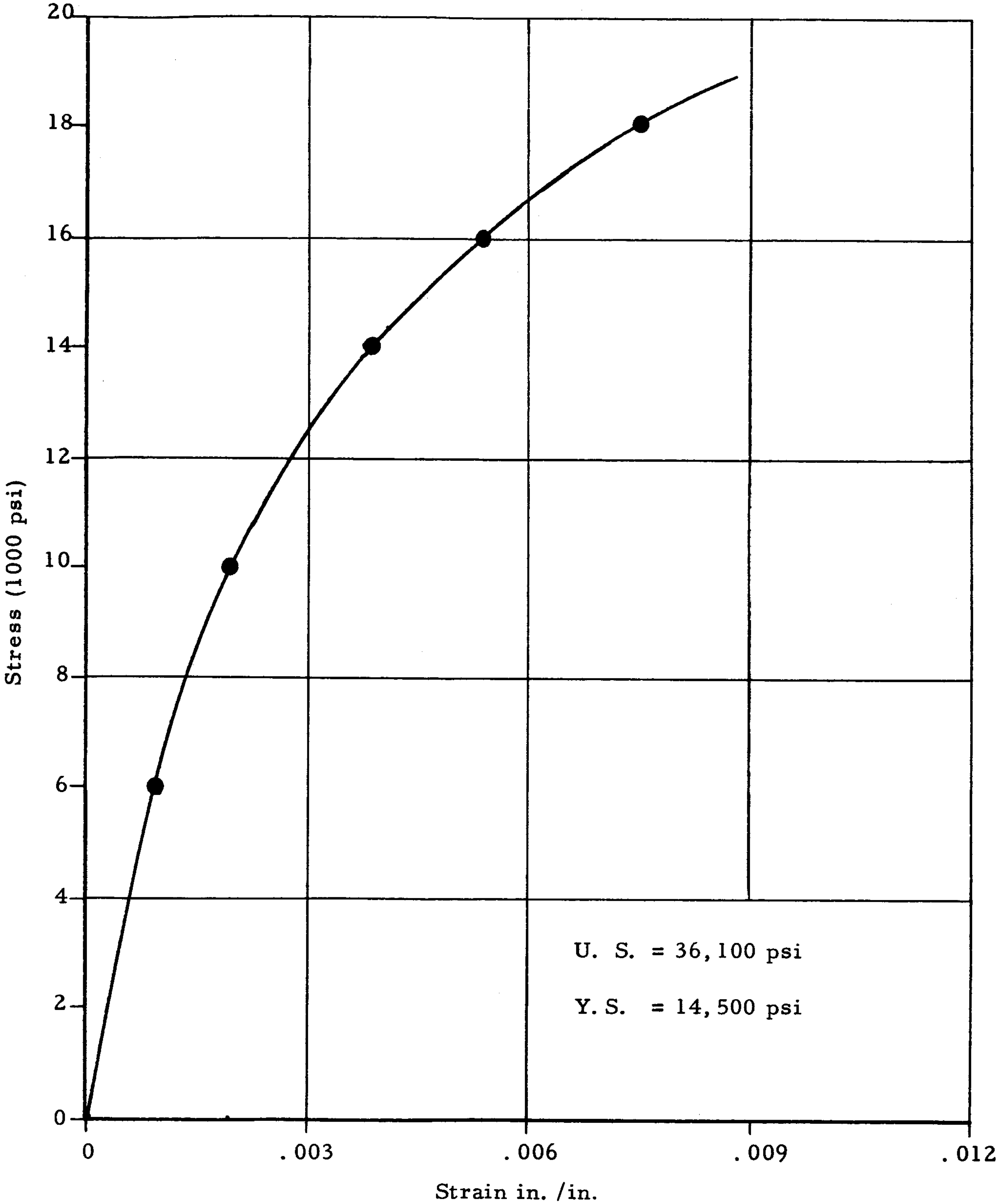


FIGURE 26. STRESS-STRAIN CURVE OF MAJOR STRESSED AXIS OF BIAXIAL TENSILE TEST, 2219-T87 ALUMINUM ALLOY WELDMENT. SPECIMEN NO. B33-2

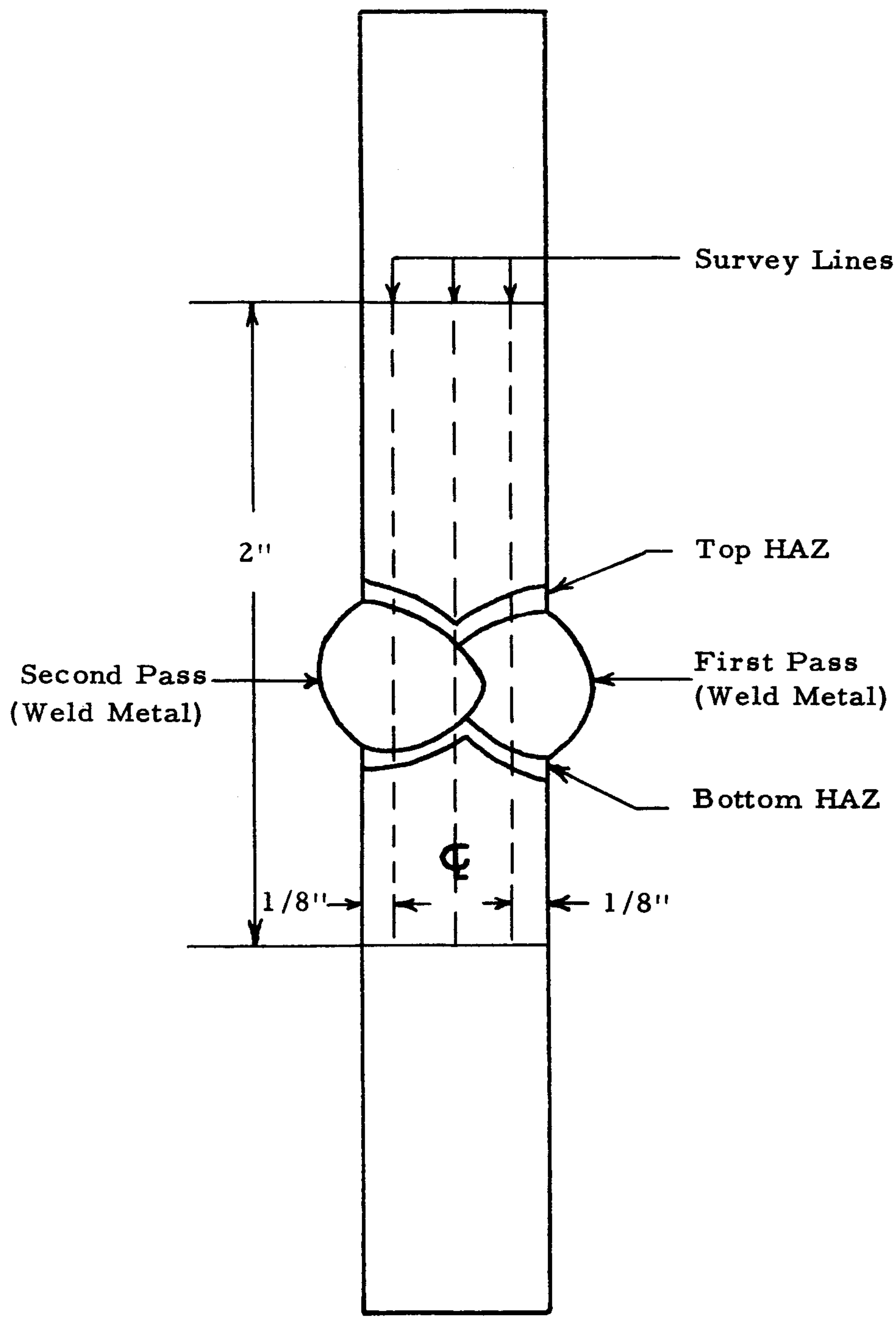


FIGURE 27. SCHEMATIC OF ELONGATION SURVEYS ON THE REDUCED SECTION OF A TENSILE SAMPLE

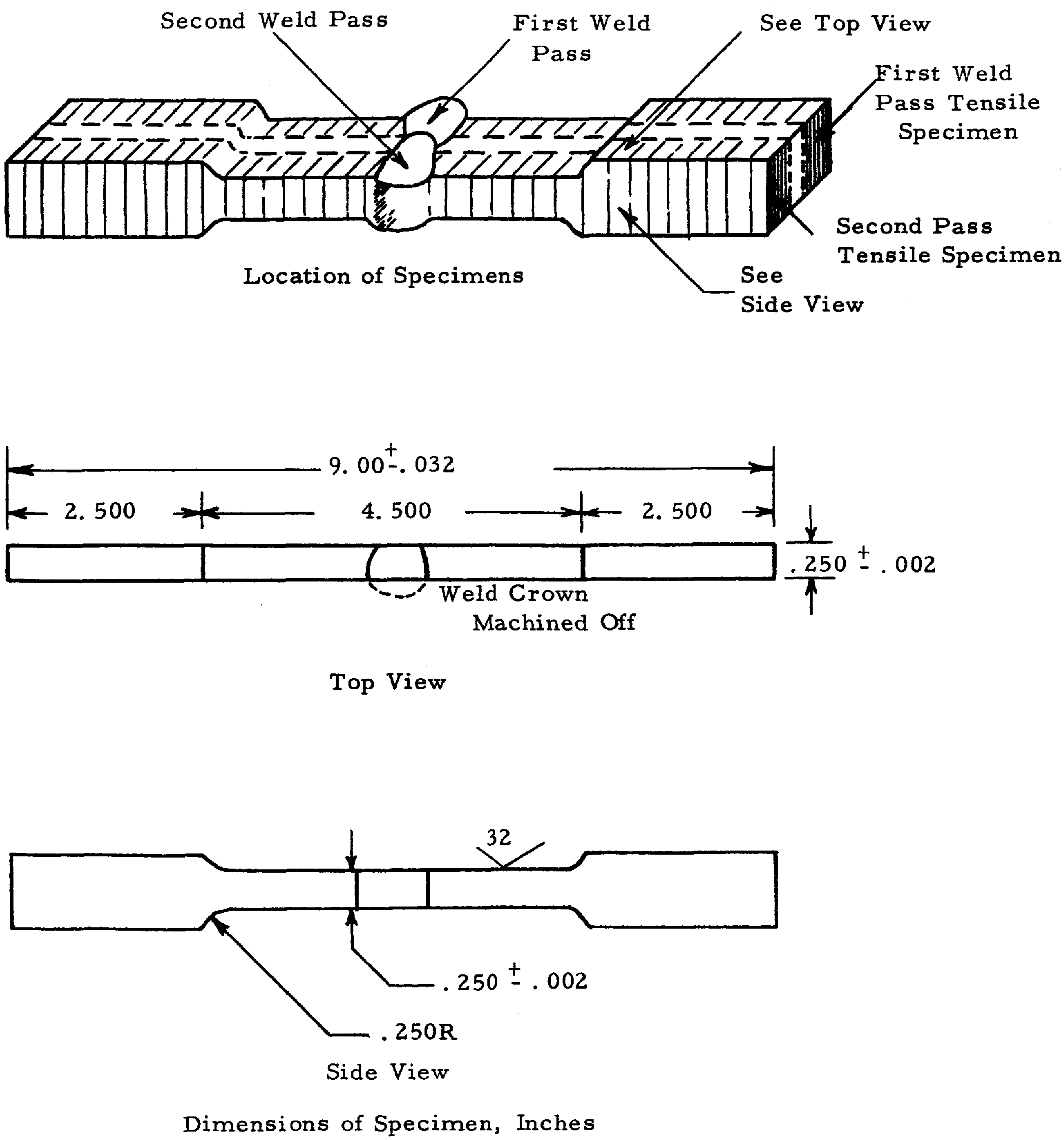


FIGURE 28. LOCATION AND DIMENSIONS OF INDIVIDUAL WELD PASS TENSILE SPECIMENS

APPENDIX A

APPENDIX A

In the Seventh Quarterly Report, Contract No. NAS8-1529 of this investigation, initial work had just begun to identify a "needle" like phase occurring in the toes of 2219-T87 aluminum weldments. A specimen was sent to Meta-Chem Laboratories, Inc., Houston, Texas for X-ray diffraction analysis. It was reported that in addition to other elements cobalt was found in the toes of the weld. Because questions were raised as to the validity of this analysis, another specimen was sent to Charles C. Kawin Company, Chicago, Illinois for wet chemical analysis. This analysis was not confined to toes of welds but rather included weld deposit in general. This company reported 0. 01 percent cobalt. Based on these two analyses it appears that cobalt is present in small amounts.